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1

GENERAL THEORY

IN this chapter it is intended to describe very shortly the basic theory of magnetic recording and to give a background for the more practical designs given later.

Firstly, it must be explained that in spite of Poulsen's historic achievements at the beginning of this century, magnetic recording is an extremely young science and has only been made practicable for the home constructor in the last year or so. To a large extent, the reason is that there was no suitable recording medium available outside laboratories. Now it is possible to get wire and coated tape from a number of manufacturers.

There are two main types of medium. Fine magnetic wire .004 ins. in diameter; and a plastic (or paper) tape $\frac{1}{4}$ in. wide and coated with either the red (Fe2O3) or black (Fe3O4) oxides of iron. Other mediums such as coated paper discs and tubes or steel tape are in use, but are neither suitable for nor available to the experimenter.

The advantages and disadvantages of tape and wire are greatly argued, but the main points are as follows:

WIRE

Cost per hour	40s.
Output on playback	Fairly high
Bulk per hour	$\frac{3}{8}$ ins. x $2\frac{7}{8}$ ins. diameter wide spool
Mechanical handling	Slightly complicated
Ease of editing	Difficult
Speed of playing	24 ins. per sec.

TAPE

Cost per hour	35s. at double track
Output on playback	Low
Bulk per hour	$\frac{3}{8}$ ins. wide x 7 ins. diameter reel at double track
Mechanical handling	Simple
Speed of playing	7 $\frac{1}{2}$ ins. per sec.

The above speeds of playing are comparable and are suitable for high quality music, other standard speeds for tape are $3\frac{1}{2}$ ins. per sec., 15 ins. per sec. and 30 ins. per sec. The first is usually used for recording speech and the last two for studio equipment.

Thus the wire scores on bulk per hour and output and the tape scores on the mechanical side, as it needs no mechanism to keep the layers wound evenly and can be handled and loaded with ease.

Now, knowing the materials at our disposal, a brief summary of the methods of recording and playing back with them is required.

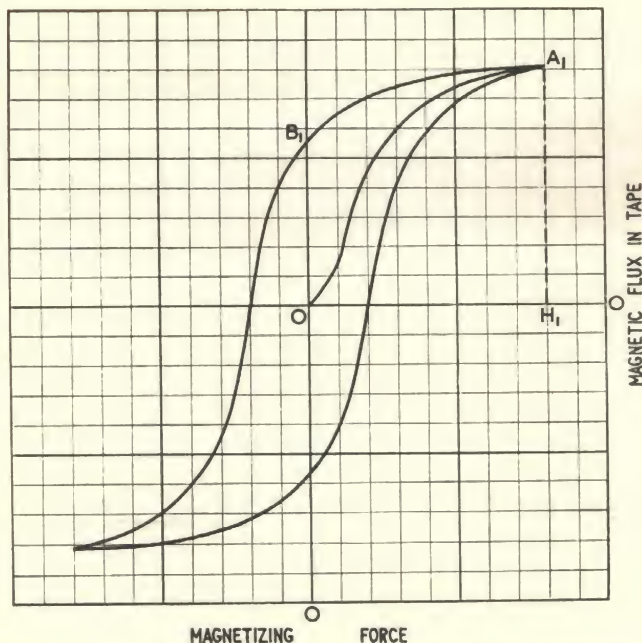


FIG. 1. MAGNETIZING CHARACTERISTIC OF TYPICAL MATERIAL, SHOWING HYSTERESIS LOOP.

RECORDING

Essentially, the aim is to magnetize the medium in such a way that magnets are formed of amplitude and wavelength corresponding to the signal to be recorded. Wavelength is used deliberately here instead of frequency as it is the important factor in recording where the medium may have different velocities for different applications. The polarity of these magnets may be either along or across the direction of motion and both are used, although longitudinal recording is becoming almost universal and will be the only method described here. The electromagnet which is used to form these magnets is called the recording head; similarly, there is a playback head and an erase head. One of the great advantages of magnetic recording is its ability to use the medium again and again, wiping out the old recording as the new one is made.

To understand how the medium is magnetized, reference must be made to its B-H curve, that is, the relationship between the magnetizing force and the magnetic flux produced by it on a

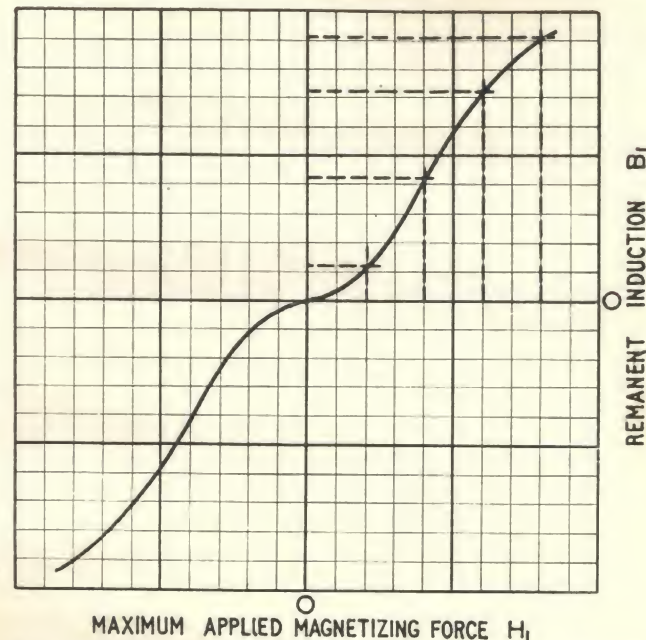


FIG. 2. REMANENT INDUCTION PLOTTED AGAINST MAGNETIZING FORCE, SHOWING THE NON-LINEARITY OF THE TRANSFER CHARACTERISTIC.

magnetic material (Fig. 1). If the medium is subjected to a magnetizing force H_1 , which then is reduced to zero, the magnetism remaining, B_1 , is found by following the initial magnetizing curve to the point A_1 , and then returning to the B axis along the line $A_1 B_1$ according to the normal behaviour of magnetic materials.

If now the values of B_1 and H_1 are plotted (Fig. 2) for different loops, as the curve represents remanent induction against magnetizing force, it will be seen that the transfer characteristic is extremely non-linear and considerable distortion would result if this were used for recording. To avoid this, the modern practice is to superimpose on the signal to be recorded a high frequency sine wave. This is made large enough so that it overcomes the initial kink in the transfer characteristic. Now the complete explanation of this so-called a.c. bias method of recording is very complex and only a very simplified version will be given here.

It is assumed that the head operates on the demagnetized medium for a definite but very small interval of time and also that

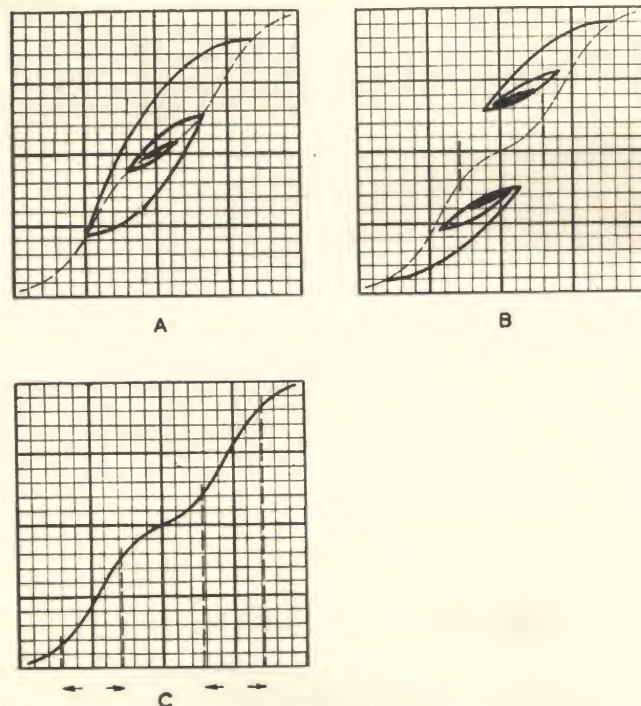


FIG. 3. SHOWING HOW A.C. BIAS ENABLES DISTORTIONLESS RECORDINGS TO BE MADE.

the field rises to a maximum and then falls gradually. The bias frequency is such that several reversals of field take place during this time. If the signal is zero at the moment of recording, the residual flux which would be left in the tape, plotted against the instantaneous field to which it would be due, would look like Fig. 3 (A), starting from the point where the field reaches its maximum. When a signal is present as well as the h.f. bias current, as represented at (B), the magnetization settles down to a value near the lowest point of the initial loop, but within all the loops. The signal component of magnetization at the gap is represented by the vertical dotted lines. If the amplitude of the bias signal and a.f. signal is such that the maximum loop always falls between points located on the relatively straight portions of the curve of Fig. 2, the transfer characteristic will be very nearly straight, too. (Fig. 3 (C).)

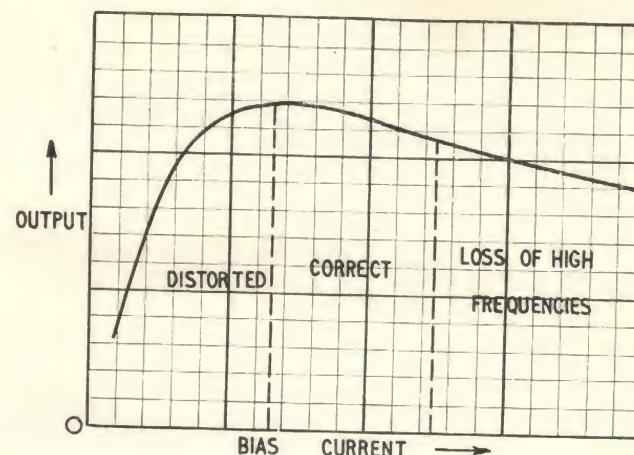


FIG. 4. PLAYBACK HEAD OUTPUT PLOTTED AGAINST RECORDING BIAS CURRENT FOR A TYPICAL MEDIUM.

Thus, by using a suitable value of bias, the recording can be made undistorted. A point to be noticed here is that if the bias is not a pure sine wave, the transfer characteristic will be displaced one way or the other due to asymmetry and so there will be some permanent magnetism remaining with no signal. This reduces the available straight part of the characteristic in one direction and so the amplitude of an undistorted recording. The amplitude of the bias must be more than a certain fixed amount, but over biasing does not introduce distortion because, when the medium is moving out of the head, there is a moment when the bias field is correct and so the only effect is a reduction of effective signal field. Fig. 4 shows the output/bias current curve for a typical medium.

The recording field is produced by a head consisting most usually of a magnetic ring with a short gap and wound with a coil. The gap is then brought into contact with the medium so that the concentrated field in the vicinity of the gap passes through the medium. It will be seen from Fig. 5 that the medium goes through a field which increases to a maximum and then decreases. If the wavelength of the bias (.00015 ins. for 50 kc at $7\frac{1}{2}$ ins. per sec.) is much less than the effective gap (.003 ins. is usual), several cycles of the bias will occur while a short length of the medium is influenced by the head. This makes certain that the material is allowed to complete its maximum hysteresis loop. Recording does not take place until the material reaches the end of the gap. The recording aperture may be defined as the distance needed for the field to fall

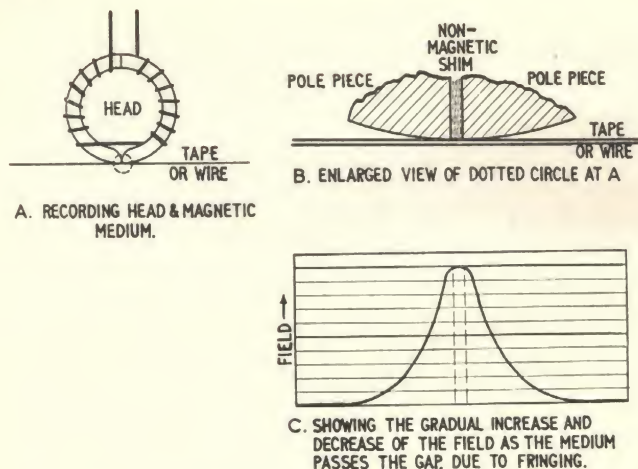


FIG. 5. SHOWING HOW A RECORDING HEAD PRODUCES THE MAGNETIZING FORCE IN THE RECORDING MEDIUM.

from maximum to a sufficiently low value for no further recording to take place. Thus, there is no need for the recording gap to be exceptionally small.

The rest of the design of the recording head depends more on the electrical than the magnetic requirements. It is usual for the impedance to be low so that there is the minimum of loss of bias due to the capacitance of the leads to the head. The iron in the head is almost invariably Mumetal or Permalloy C in order that the maximum field in the gap may be obtained. The iron is in the form of laminations stacked to give the required track width for tape. Recording wire, being thinner than the laminations, will need only a stack of one or two with a groove cut to suit the wire.

The plan of the laminations is often such as to allow an extra gap at the back which reduces the effect of unintentional permanent magnetism and also makes the general construction simpler, a coil being wound on each half (Fig. 6).



FIG. 6. TYPICAL HEAD ARRANGEMENT.

The front gap is bevelled so as to concentrate the field in the gap, the depth at this point being between .02 and .05 inches.

PLAYBACK

The state of the recorded medium may be regarded as a series of alternately polarized magnets (Fig. 7). The lower the frequency, the longer will be the magnets.

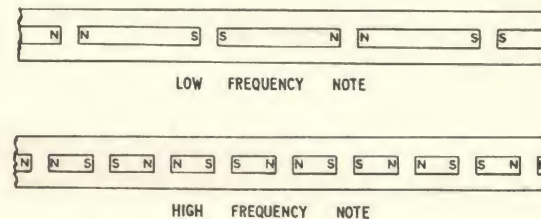


FIG. 7. DIAGRAMMATIC REPRESENTATION OF A MAGNETIC MEDIUM WITH NOTES OF DIFFERENT FREQUENCIES RECORDED ON IT.

The playback head is similar in construction to the recording head, although now the gap size is very important as it must be sufficiently small to be able to "see" the highest frequencies (shortest wavelengths) recorded (.001 ins. = $\lambda/2$ for 8 kc at $7\frac{1}{2}$ ins. per sec.). It is usual for the gap to be between .5 and .75 of the half wavelength (.0005 ins. for 10 kc at $7\frac{1}{2}$ ins. per sec.). As the magnets pass the gap, the voltage produced across the coil is proportional to the frequency of the signal. This means that a complementary response, falling with frequency, will be required in the playback circuits. The required rate of fall is 6 db per octave.

FREQUENCY LIMITATIONS

The principal limitations to frequency response are at the high frequency end of the audio spectrum. Several factors combine to make this loss drastic unless care is taken with them.

GAP EFFECT

As has already been stated, the effective gap should be roughly 50 per cent. of the shortest half wavelength to be reproduced. This means that with a physical gap of .0002 ins. (the smallest practical) and allowing 50 per cent. for fringe effects (Fig. 8), the shortest wavelength usable is about .0005 ins. This corresponds to 15 kc at $7\frac{1}{2}$ ins. per sec.

DEMAGNETIZATION OF SHORT MAGNETS

Any material if magnetized in such a way that the magnet is very short compared with its thickness, will tend to demagnetize itself. This effect will be least when the material has a high coercivity, coercivity being the ability to resist demagnetization of any sort. Now, if the medium were .001 ins. thick, the magnets would be "short" when the wavelength was of the same order. This gives a limit of about .001 ins., or 7.5 kc at $7\frac{1}{2}$ ins. per sec. The degree of demagnetization at this frequency may vary from only

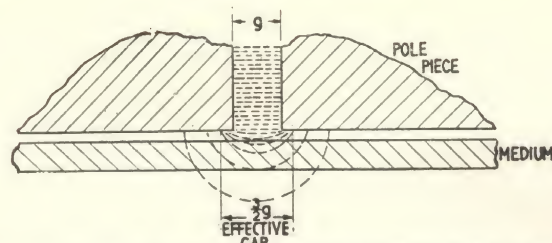


FIG. 8. LINES OF FORCE BETWEEN POLE PIECES GIVING AN EFFECTIVE GAP $3/2$ TIMES THE PHYSICAL GAP "g."

one or two db for high coercivity tape (500 Oersteds) to 10 db or so for low coercivity tape (100 Oersteds). With wire .004 ins. in diameter, the velocity would have to be increased to 30 ins. per sec. to obtain comparable results.

PHYSICAL ERRORS OF ADJUSTMENT

It has been assumed up to now that the medium was in close contact with the head. This is not always achieved, with the result that the effective gap is greatly increased (Fig. 9). A distance of

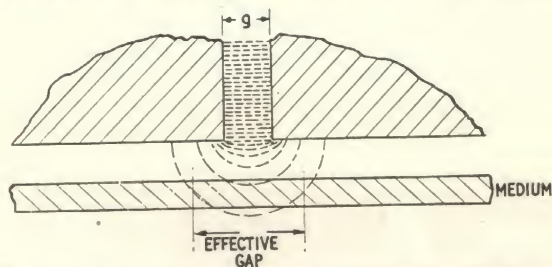


FIG. 9. INCREASE OF EFFECTIVE GAP WHEN THE MEDIUM IS NOT IN CLOSE CONTACT WITH THE POLE PIECES.

.001 ins. between the head and the medium can increase the effective gap by as much as four times; so close contact is of the utmost importance.

Also, with tape, if the angle that the playback gap makes with the direction of motion is different from that made by the recording gap, a loss of high frequencies will result (Fig. 10). If the angle is such that two adjacent cycles can just be in the gap at once, then there will be no output. Half this angle will reduce the output by some 6 db.

Even if playback and record heads are exactly aligned, as when the same head is used for both purposes, it is necessary that the tape should be kept running in line to the above degree of accuracy.

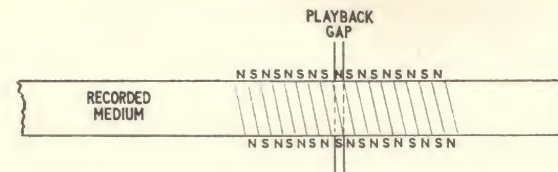


FIG. 10. PLAYBACK NOT ALIGNED WITH RECORDING GAP.

This does not occur with wire, as the angle would need to be about 45° to have the same effect.

The combination of these effects gives a very sharp fall off above the turn-over frequency. The frequency response for recording and playing back on a typical medium is of the form shown in Fig. 11. Correction for this must be made in the amplifiers; this is dealt with in Chapter 3.

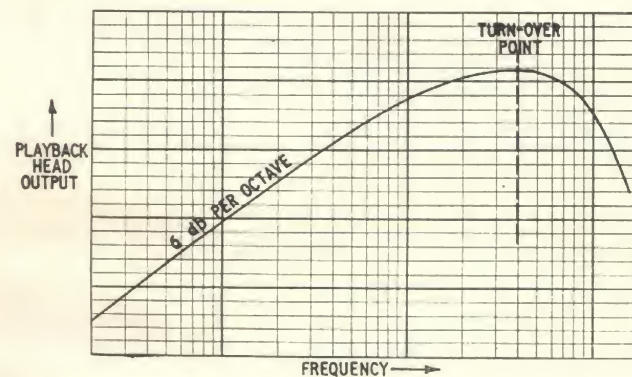


FIG. 11. FREQUENCY RESPONSE FOR RECORD AND PLAYBACK ON A TYPICAL MEDIUM.

ERASE

Magnetic recording is unique in that it is possible to erase and re-record the medium almost indefinitely. It is usual to erase by demagnetizing the medium, although it is possible to erase by magnetizing it fully in one direction. The latter gives a good erasing action, but as the medium is left magnetized, the subsequent operation of recording cannot take place as previously described and a certain amount of distortion is inevitable. Also, the medium will still be magnetized predominantly in one direction after recording and there will be an increase in background level.

ERASING BY DEMAGNETIZATION

This is usually effected by passing the medium through a strong a.c. field using a head similar to the record head, but with a larger gap. This allows a fairly large number of cycles to effect the medium, the field rising to a maximum and then falling in a similar manner to normal a.c. demagnetization. Advantage is often taken of the existing bias oscillator so that the same supply is used at different levels for both purposes. Provided the field at the gap is sufficient and the waveform is sinusoidal, the medium will be satisfactorily demagnetized.

A succession of small permanent magnets of alternate polarity and decreasing strength could be used to provide an effective a.c. field to the moving tape and so erase it (Fig. 12). Almost complete demagnetization is possible and for many purposes it would be perfectly adequate. The limitation of this method is that it is impossible to demagnetize the medium completely.

Mechanical layouts depend on whether tape or wire is being used.

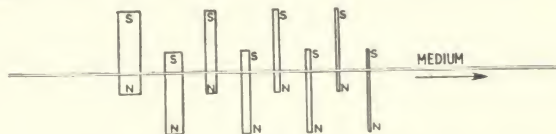
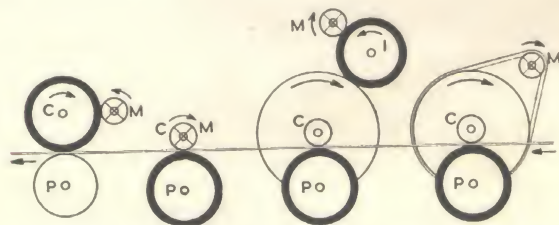


FIG. 12. ERASING BY USE OF A SERIES OF PERMANENT MAGNETS OF DECREASING STRENGTH.

TAPE LAYOUT

The tape is pulled from one reel past the head or heads by a capstan and pinch wheel at a constant speed and then wound on to the take-up reel. It will be seen that the drive to the take-up reel must vary with the amount of tape wound on. This may be done with a separate motor or via a slipping friction drive from the capstan. The capstan may be either the actual motor shaft turned down or a wheel on a separate shaft running at a relatively

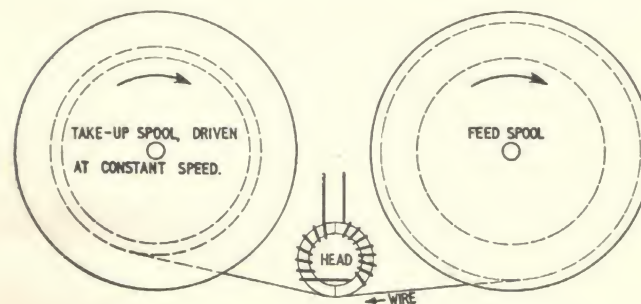


3. VARIOUS DRIVE ARRANGEMENTS. P=pinch wheel; C=capstan; M=motor; FIG. 1 = idler. Rubber-tyred wheels indicated by black circles.

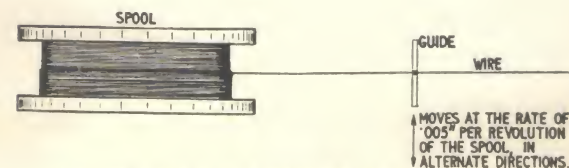
low speed and employing a reduction drive from the motor. Many variations of layout are used, a few of which are set out diagrammatically in Fig. 13. The tape is gripped by spring pressure between a pinch roller and the capstan.

Any drive method is permissible so long as the tape is moved absolutely uniformly. The take-up drive must also be smooth enough not to pass speed variations back to the capstan drive.

It is normal to provide for a fast rewind. This is usually done with a separate motor, although there are several commercial designs which have only one motor and transfer the drive from forward to reverse by using clutches or by moving an idler wheel. The advantage of simplicity goes with the use of more than one motor as the motor spindle drive and all the switching from forward to reverse is performed electrically.



A. THE SEMI-CONSTANT SPEED DRIVE LAYOUT



B. THE METHOD OF LAYER WINDING WIRE ON SPOOL.

FIG. 14. BASIC ARRANGEMENT OF SIMPLE TYPE OF WIRE RECORDER.

WIRE LAYOUT

When wire is the medium, there is a choice of two basic methods of driving: constant; and semi-constant speed. The first method is identical with the tape drive, but the second method does away with the capstan and pinch wheel, the drive being direct to the take-up spool. This spool being driven at a constant rotational speed, the wire must move faster as the spool fills up, due to its greater effective diameter. As such a small bulk of wire is used, the difference in diameter is not sufficient to make the speed variation excessive. This second method is not used for high quality equipment and usually is only found on dictating machines or similar gear.

The other peculiarity of wire transit mechanisms is the need for layer winding. A guide is moved to and fro at about 5 thou. per revolution and so winds the wire on to the spool in neat layers.

The head for a wire recorder must have a narrow slot in it and need be no wider than is necessary to provide this slot.

Apart from these differences, the technique for wire is the same as for tape.

THE AMPLIFIER

It is usual to use the same amplifier for record and playback unless a monitoring head is needed, when the separate playback amplifier is used for monitoring. For playback, a gain of around 100-120 db is needed. Some 20 db of this is thrown away in base lift to compensate for the normal rising characteristic. This means that full gain is needed at the l.f. end of the scale and so the utmost care is needed to keep the hum pick-up at a minimum. Some top boost may also be used to counteract the falling h.f. response, although this should be done mainly in recording. Apart from the above, the playback amplifier may be made to suit individual needs.

Recording requires only a very little power, 10 mW. or so, so that the gain required is not so great as for playback even using low sensitivity microphones. The feed to the head must be from a virtual constant current source, either directly from the anode of a pentode to high impedance heads or via a resistance to low impedance heads, the effective series resistance being high enough in each case to swamp the impedance of the head at the highest usable frequency. The main top correction should take place here and often takes the form of a damped tuned circuit in order to obtain a steep enough slope.

2

MECHANICAL LAYOUT AND CONSTRUCTION
(TAPE)

THE construction of the mechanical parts of a tape recorder should not present any great difficulties to anyone with normal hand tools and, perhaps, the possibility of getting a little lathe work done.

A short description of the design follows.

The capstan, driven by a gramophone motor, pulls the tape from the feed spool round the erase and record heads, whence a spring belt drive from the motor spindle turns the take-up spool and keeps the tape tight. The whole is mounted on a wooden board which will form the top of the amplifier case. The only added refinement is a separate fast rewind motor which forms the spindle and bearing for the feed spool.

As the main drive motor and capstan are the most important mechanical features of a recorder, they will be dealt with first.

The simplest and most practical main drive is an induction type gramophone motor. If this is used, the spindle will run at 78 r.p.m. and so the capstan diameter must be about 1.8 ins. for a tape speed of 7.5 ins. per sec., the best compromise between frequency response and length of playing time. This is a reasonable size for a low speed capstan. If any speed other than 7.5 ins. per sec. is required, the capstan may be made different in diameter to suit, e.g., 0.9 ins. for 3.75 ins. per sec., or 3.6 ins. for 15 ins. per sec. To provide alternative speeds, two or more capstans may be made to fit the same motor. Care must be exercised in the layout to ensure that the pinch roller has free travel far enough to suit each capstan.

An alternative design may be built up round a simple four pole induction motor running at about 1,400 r.p.m. and using the spindle of the motor itself as the capstan. To keep the tape speed to $7\frac{1}{2}$ ins. per sec. the spindle must be turned down to 0.1 ins. This is small, but is feasible if care is taken not to bend the spindle, otherwise bad flutter will occur. The pinch wheel must be fairly large (1 inch diam.) and have a rubber tyre. Whatever motor is used, it is essential that the bearings are good and of the plain variety. Ball races introduce a rumble even when new and well lubricated.

In general, the low speed capstan is preferable, being simpler and safer from a constructional viewpoint, and will be the basis of the design given in this book. The take-up drive is to be from the main motor, so a suitable pulley and spring belt is used, the spring belt being allowed to slip to allow for the variation in speed of the take-up spool. The fast rewind motor may be almost any motor with a good low speed torque. It is permissible to overrun a motor in this position as it is not in operation for more than a minute or so at a time. Thus a smaller motor may be used than for the main drive. If, however, a separate take-up motor is to be used, it should

be well underrun so that it only just gives sufficient torque to overcome friction, otherwise its low speed will cause overheating. The use of three motors means that the three main bearings are already provided and the only one left to be constructed is that for the pinch roller. This may be a great advantage for those with only simple tools and may mean that the extra motor is chosen even if the cost is greater.

The so-called tape deck or motor board should be of 7-ply wood, well seasoned, as a certain amount of heat will be produced underneath and warping would be fatal to the true running of the tape. Before mounting the motor, connect a search coil (any air-cored coil of more than 100 turns) to the input of an amplifier (the playback amplifier is, of course, ideal) and, with the motor running, move the coil round it while listening to the hum from the loud-speaker. First find the direction in which the magnitude of the hum is least by moving the search coil from point to point round the motor. At each point, rotate the search coil about its centre to obtain the maximum pick-up. In one or more directions, the pick-up will be a minimum, so, choosing the most suitable of these, next find the orientation of the field at a point about nine inches from the motor in this direction. Rotate the coil about its centre until the angle for maximum pick-up is found. The direction of the field at the point is then parallel to the axis of the coil.

Now the motor board can be laid out on the following lines:

Put the motor on one corner of the board so that a direction of minimum pick-up lies approximately parallel to one edge. Then draw a line on the board, in the adjacent corner in this direction, so that it coincides with the orientation of the field at this point. This determines the position for the record head, *i.e.*, a line joining the two gaps should be at right angles to the line just drawn (Fig. 15).

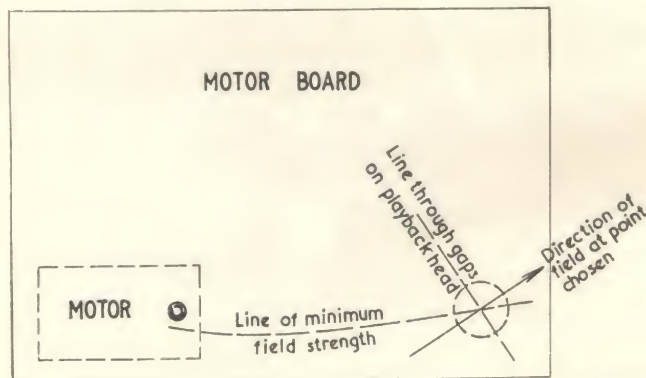


FIG. 15. HOW TO LAY OUT THE DRIVE MOTOR AND PLAYBACK HEAD FOR MINIMUM HUM PICK-UP.

The head is designed so that the tape will pull round it, which means that the front gap should point outwards. This procedure will form the basis from which the layout is made. The two tape reels and the erase head can then be laid out roughly as in Fig. 16. The tape is pulled from the feed spool round the heads to the capstan. It

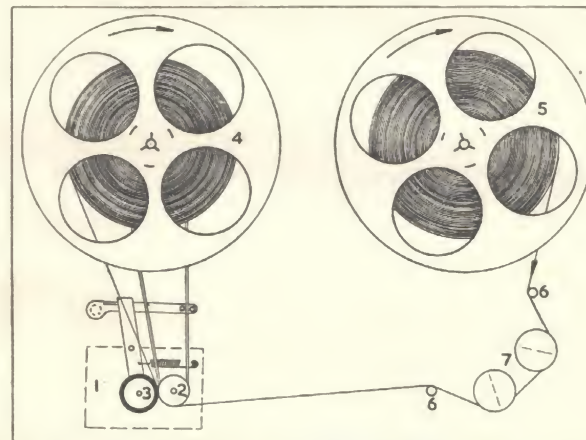


FIG. 16. LAYOUT OF COMPONENTS ON THE MOTOR BOARD OF TYPICAL TAPE RECORDER. 1—Motor; 2—Capstan; 3—Pinch wheel; 4—Take-up Spool; 5—Feed spool; 6—Tape guides; 7—Heads.

goes round the outside of the capstan and then directly to the take-up reel. The erase head is placed at an angle to the record head and immediately before it, so that the tape will run smoothly round both without any extra guides. The pinch roller is placed as shown in the diagram. The only other parts to set out now are the two guides, which are required to keep the tape running at a constant angle to the heads. These are set back slightly from the heads so that the tape can run inside them and they will not rub on the matt magnetic surface of the tape. The total length of tape between the guides should be about three inches. This gives the necessary angular accuracy without allowing any sag to take place. If a larger distance is necessary, a further guide may be needed between the heads.

Having now a fair idea of where the various parts are placed, a more detailed individual description now follows.

- (i) Gramophone motor, centre drive induction type.
- (ii) Rubber-tyred capstan wheel and pulley.
- (iii) Pinch roller and pivoting arm.
- (iv) Take-up spool spindle and pulley.

- (v) Feed spool spindle.
- (vi) Two tape guides.
- (vii) Record and erase heads.

(i) MOTOR

Reference has already been made to the motor under rough requirements. Smoothness of running is essential as there is no flywheel in the form of a turntable. This means that the motor should be checked without the turntable for smoothness of running. If the governor produces any vibration, take it away completely. The load should be constant and so there is no great need for it.

The mounting of the motor should present no difficulties as it will normally be provided with means for screwing to the gramophone motor board. The only point to watch is that the spindle should protrude at least $1\frac{1}{2}$ ins. from the top surface of the board.

As the alignment of the capstan and pinch roller is important, it is advisable to fix the latter directly on to the frame of the motor; alternatively both can be mounted on a heavy gauge steel plate.

(ii) CAPSTAN

This must be accurately machined so there is little object in using makeshift articles. The material it is made from is unimportant although in general the heavier the better. It is of paramount importance that, when fitted, the outside surface should run without any trace of eccentricity. The best method of ensuring this is to:

- (a) Drill the centre hole and make it a fit for the motor spindle.
- (b) Turn down a rod at one end to be a tight fit in this hole. Leave the rod in the lathe.
- (c) Fit the capstan on to the rod and turn the outside surface.

The dimensions should be as shown in Fig. 17. The bore is made a tight fit on to the motor spindle and the groove suitable for

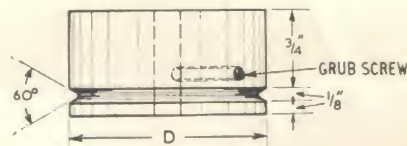


FIG. 17. MAIN DIMENSIONS OF CAPSTAN. $D=1.86$ " for 78 r.p.m.

the belt to be used. The diameter depends on the speed of the motor. If the governor has been removed, the speed must be carefully checked first and then D found from the following:

$$D = \frac{60}{\text{r.p.m.}} \times \frac{7.5}{\pi} = \frac{143}{\text{r.p.m.}}$$

The finish should be as good as possible, but not polished. Two grub screw holes should be drilled at right angles well clear of the line of the tape.

(iii) PINCH ROLLER

The pinch roller may also be turned from a solid bar in the same way as the capstan, but it is not so important in this case. Any wide rimmed wheel with a smooth surface may be used so long as it will run well and concentrically on an available spindle. The tyre may be made from any $5/16$ - $3/8$ ins. wide rubber band of suitable length. Alternatively, it can be cut from a rubber tube, so long as it is moulded with a smooth circumference. The rubber tube should be fixed to the wheel with Bostick or similar rubber cement.

The pinch wheel runs on a spindle which is fixed at its lower end to a pivoted arm about 2 ins. long. This arm is pivoted so that the pinch wheel moves radially from the capstan to allow for threading the tape and is pulled on to it by a coil spring for driving.

The construction is shown in Fig. 18. In order to keep the

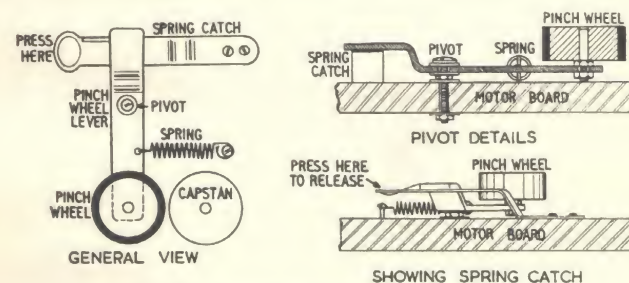


FIG. 18. PINCH WHEEL ASSEMBLY AND SPRING CATCH.

pinch roller away from the capstan during loading, a simple catch made of spring steel is used. Before bending, the shape is as shown in Fig. 19.

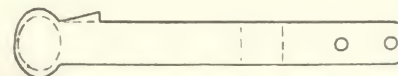


FIG. 19. SHAPE OF SPRING CATCH BEFORE BENDING.

(iv) TAKE-UP SPINDLE

This should be a vertically mounted $5/16$ ins. spindle with a pulley wheel fixed to it. From the upper surface of the pulley, there should be a small peg to engage with the spool. The bearing of the spindle presents the most difficulty as any roughness will be transmitted to the tape. A good way out is to use an old tuning condenser of the type with bearings at both ends of the vanes. Take off the vanes and slacken the bearings off till the spindle is

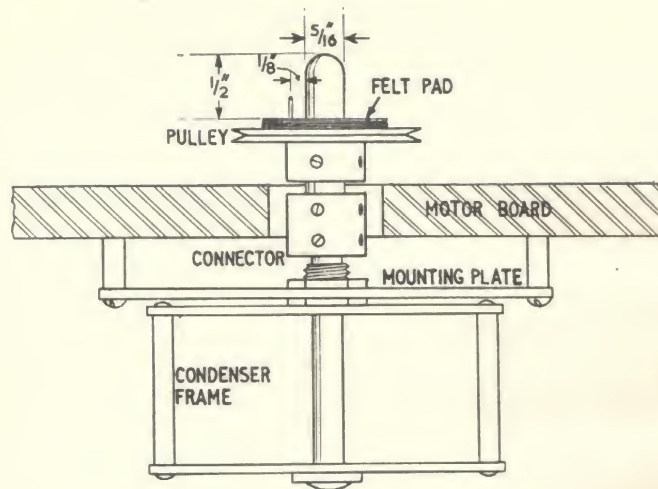


FIG. 20. TAKE-UP SPINDLE AND PULLEY CONSTRUCTION.

quite free. When this is mounted on the board, there will be the $\frac{1}{4}$ in. spindle sticking out. This may be adapted to take a $\frac{5}{16}$ in. rod by drilling out a standard $\frac{1}{4}$ in. spindle connector to $\frac{5}{16}$ in. for half its length. Then the $\frac{1}{4}$ in. spindle of the condenser is sawn off, leaving $\frac{1}{4}$ in. to go in the connector. A piece of $\frac{5}{16}$ in. rod is then fixed on the top and carefully trued up. A pulley wheel is mounted on this spindle with a small peg sticking out from its top surface. Then the spool is allowed to rest on the pulley spaced from it by a felt washer. The condenser is mounted on a plate under the motor board so that the thickness of the board allows for the added height of the connector (Fig. 20).

The diameter of the pulley should be made three-quarters of the diameter core of the spool cores. This will make sure that the spool will always tend to run faster than is necessary to wind up the tape. The slip occurs in the spring belt drive which is adjusted so that it is only just tight enough to overcome the friction of the take-up spindle.

(v) FEED SPINDLE

If no fast rewind motor is used, the feed spindle can be constructed similarly to the take-up spindle except that the bearings are left very slightly tight. The pulley is not required, but a similar disc should be mounted on the spindle for the spool to rest on.

If a motor is used for rewind, its spindle should be adapted to take the spool holding assembly as above. A small friction pad may be needed to press on the under side of the disc to prevent

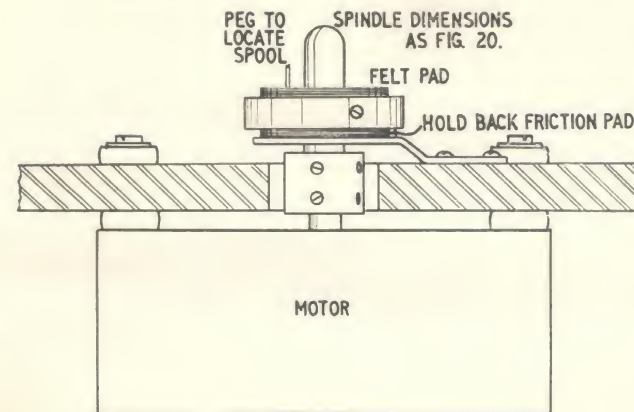


FIG. 21. FEED AND REWIND SPINDLE CONSTRUCTION.

overrunning during forward drive (Fig. 21).

It is not advisable to employ the fast rewind without disengaging the tape from the capstan and the heads.

(vi) TAPE GUIDES

The two most important guides are those on each side of the heads. These must have slots in them only just wider than the tape. The width of the tape being .245 ins., the guides should be .255 ins. plus or minus .003 ins. It is worth making a bar with one end the lower and the other end the upper limit in width. This can then be used to gauge the slots. The guides themselves are best made by turning out of $\frac{1}{4}$ in. steel rod to the shape shown in Fig. 22. Being round they can be turned through about 45° if there is any wear, so a new face is presented. It is essential that the tape be made to run flat at the bottom of the slot in the guide.

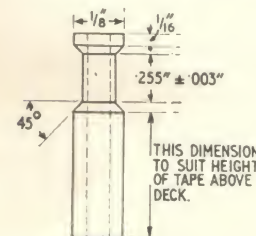


FIG. 22. DIMENSIONS OF TAPE GUIDE.

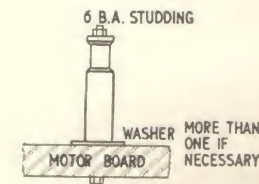


FIG. 23. TAPE GUIDE MOUNTED ON MOTOR BOARD

If necessary, the guide can be filed out of any suitable material to the above shape, though great care should be taken not to leave burrs or sharp edges. If the turned guide is used, it may be mounted on a 6BA tapped pillar and adjusted for height by inserting washers underneath it (Fig. 23). It may be necessary to have another guide near the capstan to maintain the height of the tape, but this need only be of the simplest construction and great accuracy is not needed.

(vii) RECORD AND ERASE HEADS

Record and erase heads are dealt with separately in Chapter 4.

When a rewind motor is used, a slight modification of the take-up spool mounting is needed to include a brake which is applied when both motors are off. An idler is also introduced into the take-up belt drive, so that during forward drive the idler holds the belt tight, but when the rewind motor is switched on, the idler is moved away so there is only a very slight friction for the rewind motor to work against. This is not as complicated as it sounds, the whole mechanism being shown in Fig. 24.

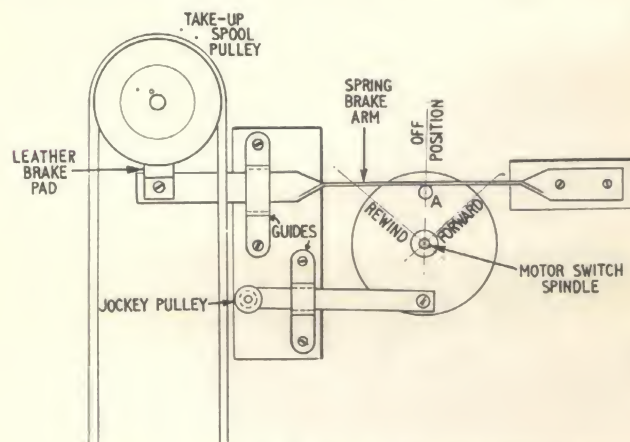


FIG. 24. BRAKE AND JOCKEY PULLEY OPERATING MECHANISM CONSTRUCTION.

The spindle of the motor switch has a $1\frac{1}{2}$ ins. dia. circular plate fixed to it. Two 6 BA holes are drilled on the plate opposite to one another. One hole is for the brake operating stud A and the other is loosely bolted to the jockey pulley operating strip. The brake arm is spring steel screwed to the motor board so that the leather brake pad is just clear of the pulley wheel. Then, when the switch is in the off position, the stud A presses against the brake arm and puts the brake on. On either forward or rewind,

the brake is off. Fig. 24 shows the "off" position; the other positions are indicated by chain dotted lines.

The jockey pulley is a small, deep-flanged pulley wheel mounted on its sliding operating strip, so that a 90° turn of the motor switch disc will bring the pulley into engagement with the take-up belt. Appropriate guides, mounted on wood blocks, provide suitably rigid operation of both the brake and jockey pulley. Another block is used to mount the fixed end of the spring brake arm.

To obtain a good range of movement, the motor switch should be set so that 60° instead of 30° rotation is needed for each operation. This is done by using only alternate positions on the normal type of rotary switch.

This operating plate may be employed to do any other small operations, such as lifting the pinch wheel, etc., in a similar manner, so that the whole recorder may be mechanically controlled by one knob.

AMPLIFIERS

THIS chapter includes the whole of the electrical side of the recorder, *i.e.*, motor switching, power pack, bias, oscillator, etc.

The block schematic of a complete record and playback equipment is shown in Fig. 25. Two amplifiers, two oscillators

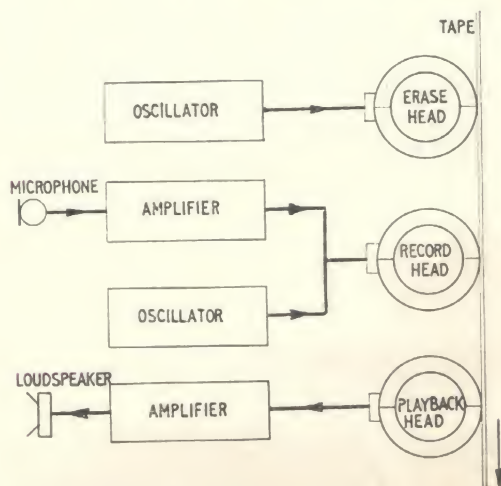


FIG. 25. BLOCK DIAGRAM OF COMPLETE ERASING, RECORDING AND PLAYBACK OPERATIONS.

and three heads are shown. By using a system of switching, the equipment can be reduced to one amplifier, one oscillator and two heads. For this purpose the amplifier must suit record and playback, the oscillator must supply both erase and bias currents and the playback head is also used for recording (Fig. 26). First, we will deal with the amplifier.

AMPLIFIER

The most arduous task this has to perform is in playback, where the gain, before any correction is made for frequency response, must be between 100 and 120 db, depending upon the overall frequency response required and power output.

The output from the head, stepped up to an impedance of 50K, will be of the order of 5 mV. Thus, if anything like 40 db of

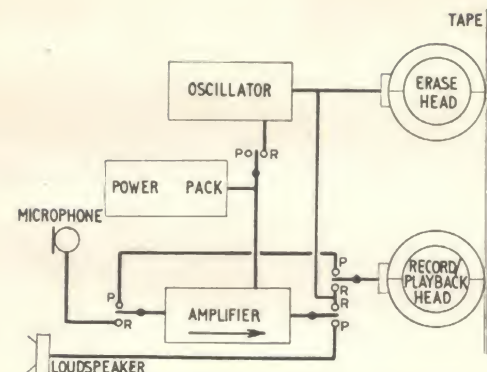


FIG. 26. BLOCK DIAGRAM OF A SIMPLIFIED ERASE, RECORD, PLAYBACK SYSTEM, USING SWITCHING.

signal to noise is to be attempted, the input circuits of the amplifier must be such that there is no more than 50 μ V of hum and noise effectively at the grid of the first valve. This is quite a low figure and great care is necessary to achieve it.

The frequency response of the recording process is shown in Fig. 27, the upper curve being for the high and the lower the low coercivity tapes. A practical record and playback head is assumed.

It is usual to correct for the low frequency loss in the play-

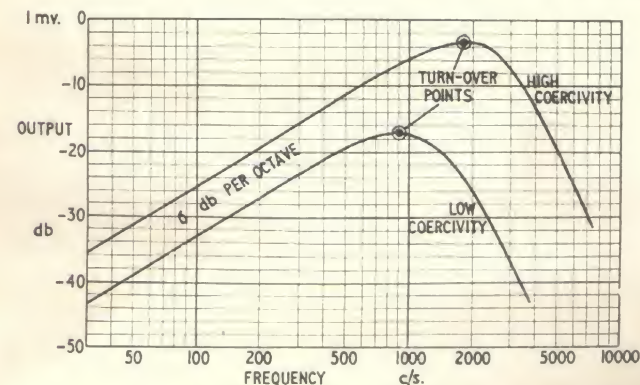


FIG. 27. RECORD/PLAYBACK FREQUENCY CHARACTERISTIC OF HIGH AND LOW COERCIVITY TAPES.

back amplifier and the high frequency loss in recording. In this way, the record head and tape are not overloaded with excessive low frequencies and the playback amplifier need not peak at high frequencies, thus producing more h.f. noise from the early stages than necessary. The high frequencies are unlikely to overload on record owing to their lower energy content. The amplifier shown here will not have more than a few watts output as this is normally sufficient and avoids complication; the output circuits can, of course, be modified for a higher power to suit individual tastes. The input circuit is shown as for a low impedance head, using a 40:1 microphone transformer (Fig. 28).

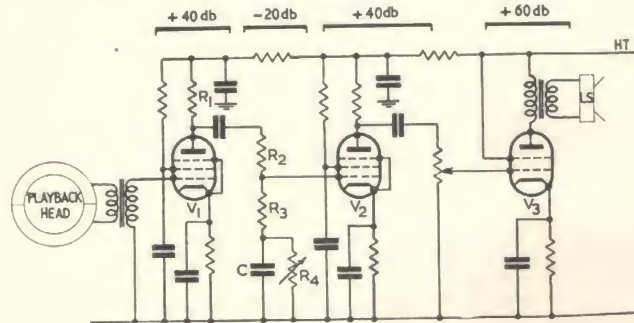


FIG. 28. PLAYBACK AMPLIFIER CIRCUIT.

The correction takes place between V_1 and V_2 , as although a little extra screening is needed to avoid hum pick-up, this avoids the difficulty otherwise of finding a valve for V_2 capable of driving the output valve via a circuit with an insertion loss of over 20 db. The gain per stage and loss in the correction network is given in db and is meant only as a rough guide. As the input is always a pick-up head, no overloading of V_2 is possible and so the volume control may safely be placed between V_2 and V_3 . The correction circuit is a normal bass lift circuit (Fig. 29). It may be designed as follows, assuming the coupling condenser to be amply large:

The circuit reduces to the equivalent shown in Fig. 29, where the resistances R_A and R_B have the values there indicated, in terms of the circuit resistors of Fig. 28. These assume that the a.c. resistance of the pentode V_1 is so high compared with R_1 that it can be ignored. If a triode stage were used, the shunting effect of its a.c. resistance across R_1 would have to be included.

The type of response produced is shown as Fig. 30. The maximum attenuation is determined by the ratio of R_A to R_B . The frequencies f_{low} and f_o are determined by equating the reactance of C to R_A and R_B respectively. Values giving the response of Fig. 30 are R_1 , 220 K; R_2 , 330 K; R_3 , 18 K; R_4 , 500 K; and C , .006 μ F. Using the equations for R_A and R_B , these evaluate

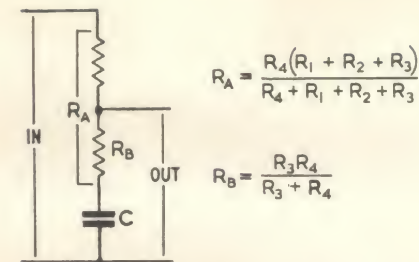


FIG. 29. BASS LIFT CIRCUIT AND EQUIVALENT VALUES IN TERMS OF ACTUAL CIRCUIT COMPONENTS.

to 250 K and 17 K respectively, giving a ratio of 15:1 or about 23.5 db.

The final adjustment of correction circuits can never be attempted until the whole recorder is working. The above figures are merely intended as a rough guide for preliminary tests.

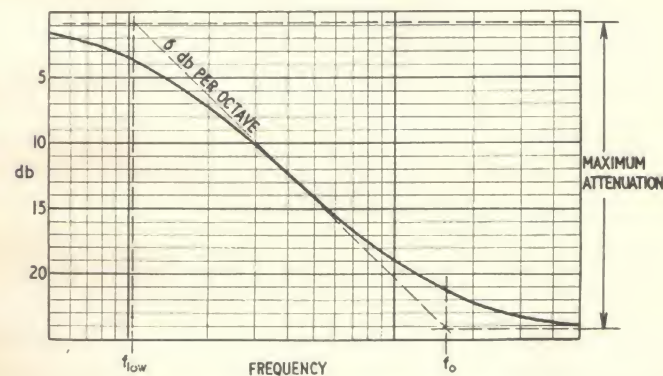


FIG. 30. BASS LIFT RESPONSE CHARACTERISTIC.

The recording amplifier is based on the above circuit so as to have the minimum of switching (Fig. 31).

Apart from input and output circuits, the only switching needed here is for the correction circuits. Again, a low impedance head is shown and is fed from the cathode of V_3 via a 25 μ F condenser. A meter circuit is provided in the anode of V_3 to set the recording level and as V_3 is a pentode, little distortion from the rectifier can get back into the head. The input circuit is shown for a crystal microphone, but this can be modified to suit whatever

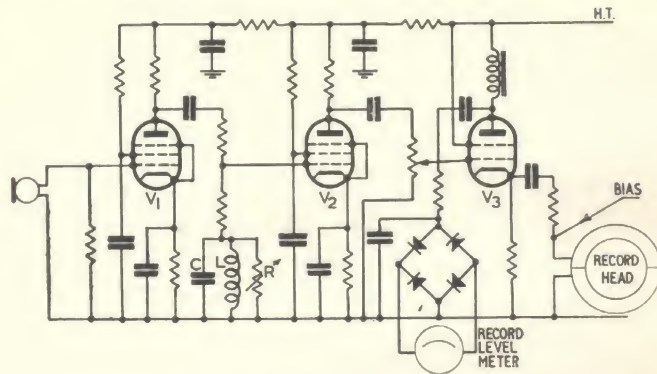


FIG. 31. CIRCUIT OF RECORDING AMPLIFIER.

signal source is to be used by fitting jacks with built-in attenuators.

The correction circuit used on record is a damped tuned circuit, which gives the sharp rise needed to overcome the steep cut off on the recording characteristic above the turn-over frequency. If f_{hi} is the highest frequency required, then L and C must resonate at f_{hi} so that

$$\frac{1}{LC} = 2\pi f_{hi} \dots \dots \dots (a)$$

L is chosen so that its reactance is roughly $\frac{1}{2} R_b$ at f_{hi} , this gives a good compromise between steepness of rise and maximum lift. Thus:

$$2\pi f_{hi} L = \frac{R_b}{2} \dots \dots \dots (b)$$

R_A and R_b are found from the maximum amount of top lift desired. This is very roughly the same as the base lift used for playback and the same values of 250 K and 17 K can be used (Fig. 32).

Now from the value for R_b and equations (a) and (b) L and C are calculated. If f_{hi} is 8kc, $L = 170$ mH and $C = .0025 \mu F$.

R damps the tuned circuit and is used to adjust the amount of top lift and the steepness of rise to suit any particular head and tape. It should be a variable resistance, say a $\frac{1}{2}$ megohm volume control. It is very important that the inductance should be magnetically screened in a steel can to avoid hum pick-up.

The combination of the two amplifiers into one piece of equipment with switches is shown in Fig. 33.

A certain amount of feedback has been included in the playback amplifier from the output transformer secondary to V_3

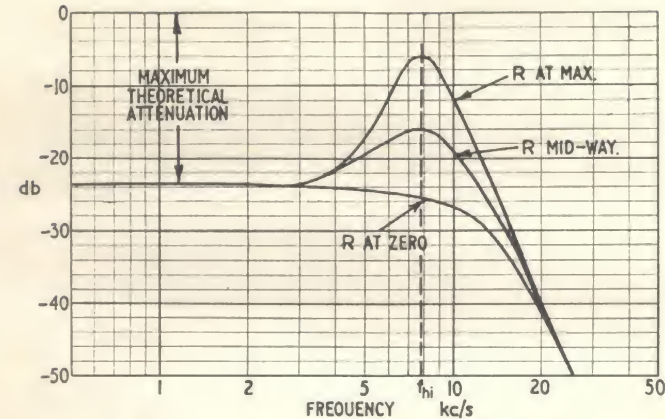


FIG. 32. TOP LIFT RESPONSE CHARACTERISTIC AT DIFFERENT SETTINGS.

cathode. If the speech coil is 3 ohms, about 6 db of feedback is obtained. If it is 15 ohms then a resistance may be needed in series to reduce the feedback to the above amount.

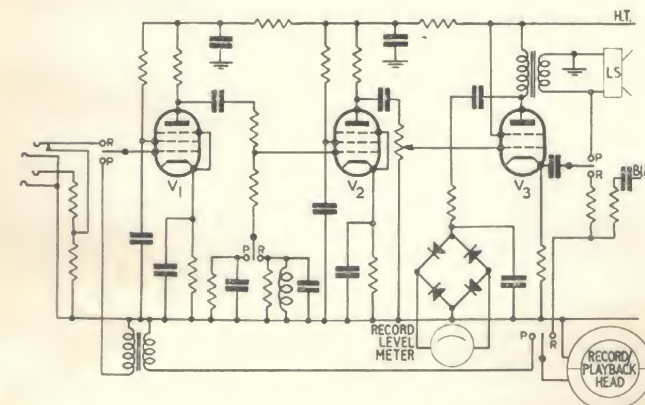


FIG. 33. COMBINED RECORD/PLAYBACK AMPLIFIER WITH SWITCHING.

OSCILLATOR

The bias and erase oscillator is a single valve, of the same type as the output valve. No hard and fast rules need apply here and any type of oscillator may be used, provided the output is sinusoidal and the power available for erase is between 2 and 5 watts depending on the tape to be used. A normal Hartley circuit is used here as being well-tried and simple to adjust (Fig. 34). The frequency

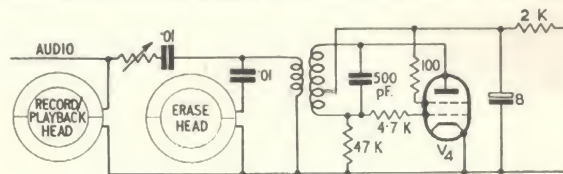


FIG. 34. CIRCUIT OF BIAS OSCILLATOR.

should be about five times the highest recording frequency, 50 kc. being the usual value taken. The heads are fed from a separate winding, giving an output impedance of about 100 ohms. A low impedance erase head is almost essential to avoid large losses in the leads to the head and to simplify its construction.

The frequency is controlled in practice by the mica capacitor across the oscillator coil, but the load imposed by the erase head and to a lesser extent the record head have a considerable effect. Although the frequency is not critical, it is as well to check it after the heads are connected and the bias level has been set. It is important to remember that it is the current through the heads that matters, so that while the oscillator is being adjusted, a current meter is needed capable of reading accurately up to 50 kc. current between 50 and 500 mA. If any difficulty is found in getting sufficient erase current, it is good practice to tune the head. This is done merely by adjusting the feed capacitor until the current peaks. About 0.1 μ F is right for the head described in this book. A similar procedure may be used with the bias feed, the capacitor being required anyway to hold off the low impedance of the erase head and oscillator output winding from the audio frequencies in the record head. It may also be found possible, by adjusting the values of the series capacitors, to improve the wave form of the current to the heads. This is of the utmost importance if background noise and distortion are to be minimised. If an oscilloscope is available, it may be connected across a low resistance (not more than 10 ohms) in series with the head, then the waveform can be seen at the same time as the relative amplitude of the current. The oscilloscope amplifier should be good to 250 kc. or so in order to be certain of seeing the true waveform.

If space and cost will allow, it is a great advantage to have a buffer stage between the oscillator and the heads. This will make it possible to obtain a very nearly pure sine wave current through the heads. The circuit will be similar to a small low frequency

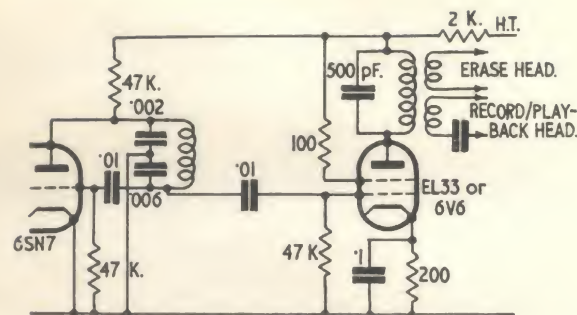


FIG. 35. ADVANCED BIAS OSCILLATOR, TO GIVE IMPROVED WAVEFORM.

transmitter, using for example half a double triode as oscillator and an output pentode as a class C amplifier. The bias may be taken either directly from the oscillator or from a separate winding on the amplifier tuned circuit (Fig. 35).

A compromise between the above two circuits is to use a Hartley oscillator with the addition of an extra tuned circuit in the anode feed. The coupling coils for the heads are wound on the latter. Like many compromises, it has neither the simplicity of the first circuit nor the quality of the second, but is popular in spite of this.

POWER PACK

The power pack has little of special interest. Once the current requirements are known, it can be designed on normal lines. Full-wave rectification is preferable from the hum point of view and adequate smoothing is required. If weight is of importance in the equipment, it is quite possible to do without a choke and rely on high capacity electrolytics and resistance for smoothing. A 60 + 100 μ F in combination with a 500 ohm wire wound resistance is adequate for the low consumption amplifier described here (Fig. 36).

If resistance smoothing is used, a rise in voltage will occur on playback as the h.t. to the oscillator is switched off. This has been found to be of little importance as the maximum gain and output are required on playback anyway, and the rise should not be sufficient to overrun any of the components.

Now that the various parts of the circuit have been discussed, they will be put together with the necessary switching as shown in Fig. 37.

This is just about the simplest circuit possible, but despite this and its limited power output, very fine results can be obtained.

It should be noted that the bias is removed by switching off the h.t. supply to the oscillator, not by disconnecting the erase head. This is important, because the latter might leave the head magne-

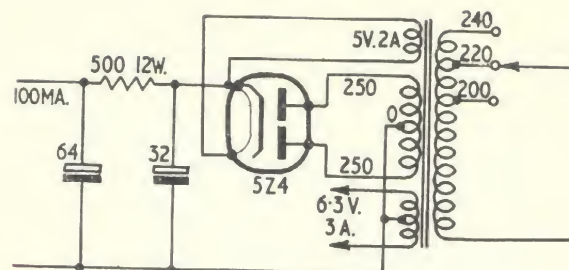


FIG. 36. POWER PACK CIRCUIT.

tized, depending on the exact instant in the 50 kc period when switching off occurs; removing the h.t. supply from the oscillator allows the oscillations to "die," so demagnetizing the erase head completely, until it is again wanted for erasing.

However, if a higher quality output stage is needed with more power, Fig. 38 shows a circuit using push pull 6V6's. Some 12 db of feedback is provided and a separate amplifier for the record level meter. An improved oscillator is shown and a greater variety of input levels and impedance is possible for recording. With the switch in the centre position the amplifier may be used for general purposes with provision for normal bass boost as required with low level pick-ups and for PA work using microphone, gramophone or tape input. It is intended for high quality work, but does not venture into the studio quality grade where a separate monitor amplifier is needed to check on everything being recorded, for which three separate heads are required.

For studio work signal to noise ratio must be about 60 db, and distortion less than 1 per cent., so a professionally made head is essential where the laminations are annealed after the grinding has been done. Also, a Mumetal screen is essential over the playback head. The wow must also be less than is obtainable with the simple equipment described here.

However, it is not difficult to add a third head and a separate record amplifier to the circuit. The amplifier can be similar to that of the first circuit shown. The switching is simplified, as may be seen in the block diagram (Fig. 39).

The play/record switch for Amplifier A is wired permanently as on record, and the switching for Amplifier B is reduced to PA and playback. If no PA facility is required, this may be omitted and the only operation needed to change from record to playback is switching on the oscillator and turning up the gain of the record amplifier. A break circuit jack for a pair of earphones is needed on the playback amplifier so that the speaker is muted when the monitoring 'phones are plugged in.

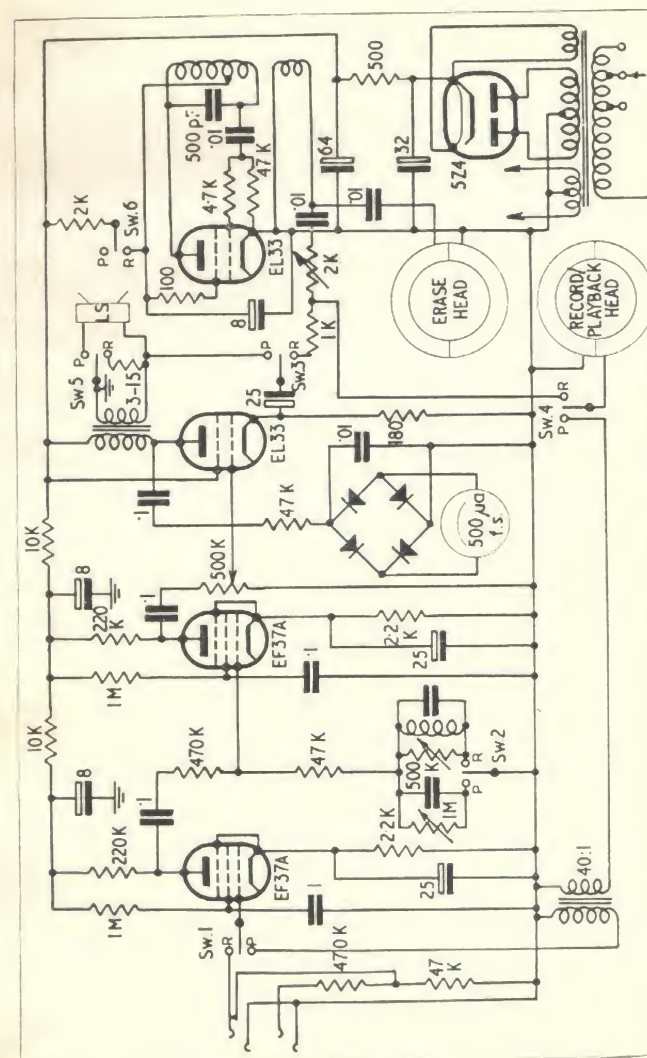


FIG. 37. COMPLETE CIRCUIT FOR RECORD/PLAYBACK AMPLIFIER EQUIPMENT.

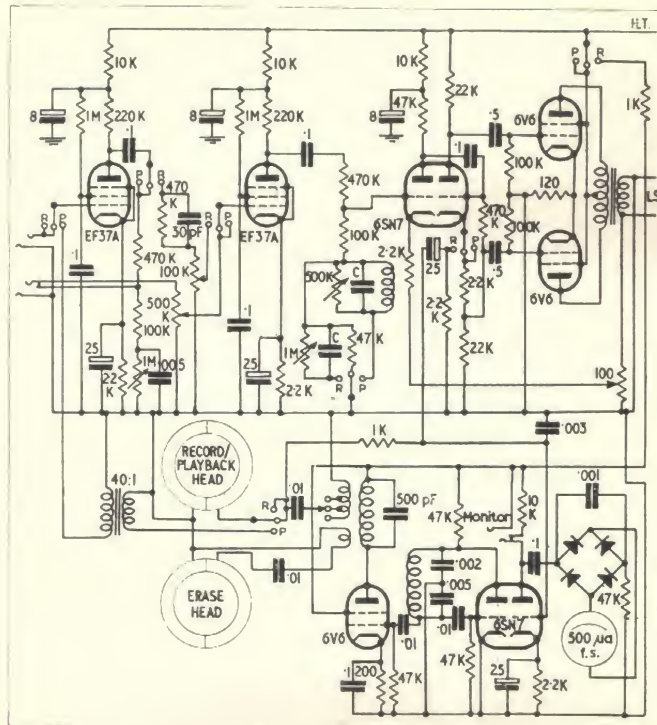


FIG. 38. ADVANCED RECORD/PLAYBACK AMPLIFIER CIRCUIT. II

CONSTRUCTION

Circuit 1.—This amplifier can be built on a single chassis if the layout is carefully arranged. Fig. 40 shows a suggested layout using normal construction. The actual dimensions will depend on the size of the components and the few minutes experimenting for position on a piece of paper before constructing the chassis are very well repaid. The points to be watched are:

- Hum pick-up from mains transformer to input transformer.
- Hum pick-up from mains transformer to output transformer.
- Capacitance pick-up between oscillator circuit and input circuit.
- The wiring of the record/playback switch.
- The earthing of input and output stages.

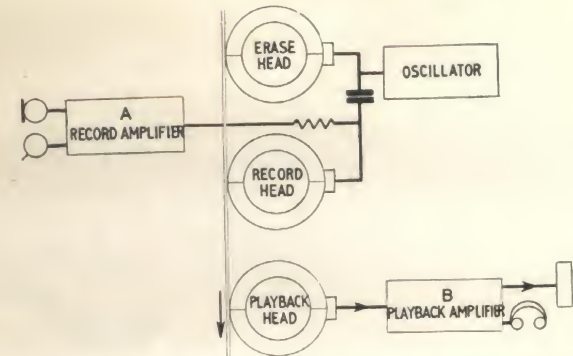


FIG. 39. BLOCK DIAGRAM OF EQUIPMENT USING THREE SEPARATE HEADS

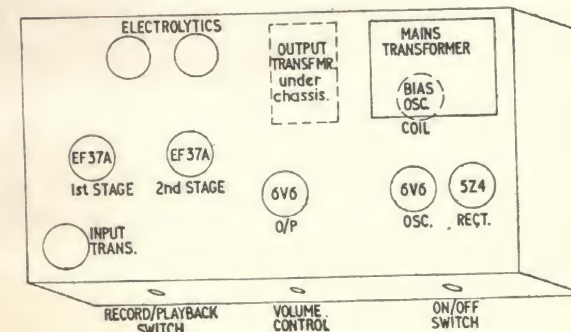


FIG. 40. RECOMMENDED LAYOUT FOR AMPLIFIER I.

HUM PICK-UP FROM MAINS TRANSFORMER TO

- INPUT TRANSFORMER AND
- TO OUTPUT TRANSFORMER

(a) and (b).—Fig. 41 shows the direction of maximum hum radiation or pick-up for the conventional type of transformer. If there were no metal chassis, the best arrangement for avoiding pick-up would be as shown in this diagram, where the two components have their axes at right angles. But the chassis complicates matters, due to its effect on the magnetic field.

Aluminium chassis is better than steel or iron, because the only effect is due to electromagnetic induction, that due to magnetic

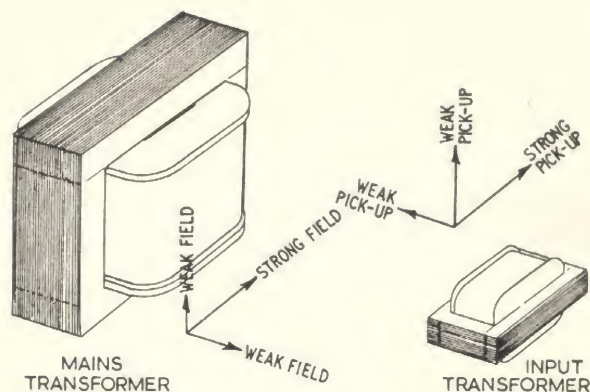


FIG. 41. DIRECTIONS OF STRONG AND WEAK FIELD RADIATION AND PICK-UP OF TRANSFORMERS, SHOWING RECOMMENDED POSITIONING, WITHOUT TAKING PROBABLE EFFECT OF CHASSIS INTO ACCOUNT.

induction being avoided. Fig. 42 shows the three conventional methods of mounting. For conveying hum to or from the chassis, that at (A) is the worst, and that at (C) the best, so where possible the last should be used.

The input transformer will usually be screened in a Mumetal or other magnetic screening case, to prevent pick-up. However, it is still advisable to provide for orientation to find the minimum hum pick-up position where high gain is used. It should, of course, be kept well away from mains transformer or smoothing choke (if used).

If the mains transformer is mounted as at Fig. 42 (C) to avoid hum field entering the chassis, the output transformer may be mounted as at Fig. 42 (B), so that it can have its axis at right angles to that of the mains transformer.

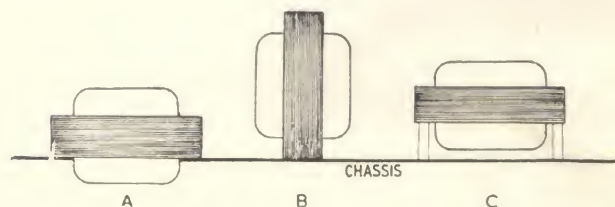


FIG. 42. SHOWING THE THREE BASIC WAYS OF MOUNTING A TRANSFORMER ON A CHASSIS. (FOR EFFECT ON HUM TRANSFER SEE TEXT).

CAPACITANCE PICK-UP BETWEEN OSCILLATOR CIRCUIT AND INPUT CIRCUIT

(c)—The simplest method of keeping this down is by separating the two parts of the circuits as far as possible and by adequate screening. The oscillator coil may even be mounted on the end of the chassis and outside it, but usually this should not be necessary. Any lead carrying the feed to the erase head or bias should be screened. Even if great care is taken, a certain amount of bias frequency current will find its way into the input circuit, but this is not disastrous as the bias has to be on the record head anyway. So long as there is not enough to overload any stage or materially affect the amplitude or waveform of the bias, it does not matter. If necessary, a small capacitor may be connected from the grid of V_2 to earth, of such value that the bias frequency is severely attenuated, but the audio frequencies are unaffected.

THE WIRING OF THE RECORD/PLAYBACK SWITCH

(d)—The basic system for avoiding hum or feedback at the switch is to keep input circuit contacts adjacent to low potential or earthy contacts and separate from a.c. or output circuits. Assuming a two bank switch, Fig. 43 gives a suggested layout using the switch numbering of Circuit 1 (Fig. 37). The blank sections are connected to earth to improve the screening.

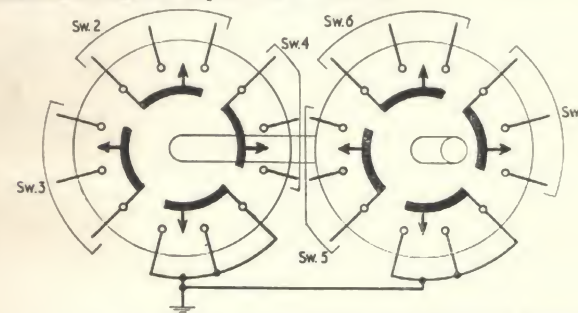


FIG. 43. SUGGESTED DISPOSITION OF CONTACTS ON PLAY/RECORD SWITCH FOR AMPLIFIER I, TO AVOID UNDESIRABLE TRANSFER.

THE EARTHING OF INPUT AND OUTPUT STAGES

(e)—The earth connections on any high gain amplifier are extremely important. The golden rule is to wire each component to a single earth point with a separate piece of wire. This is tedious, but thoroughly effective in ensuring that there is no common impedance in the earth returns of high and low level points. It is often permissible to bond the earth returns of one stage together and then connect that to the single earth point. This can be done with V_2 , but it is not advisable with V_1 or V_3 as there is so much in common between these end stages due to the head

switching. Grid leaks may often be taken to a nearby earth connection to avoid having long leads, but in no circumstances should the chassis itself be used as a conductor, *i.e.*, connection to it should be made at one point only. A good method is to have an earth bus bar of 14 swg tinned copper and take all the earth leads associated with each stage to the same point along it. The end by the input stage should be connected to the chassis. If all these precautions are taken, there should be no trouble from unexpected hum or instability. Details of components now follow.

OSCILLATOR COIL

The Oscillator Coil can be constructed on an old transformer bobbin. The primary should have an inductance of about 10 mh and is tapped one-quarter of the way up. It is unlikely that a ready-wound bobbin will be suitable, so this component must be wound from scratch. A bobbin to suit a $\frac{1}{2}$ in. square core is used. It should first be wound with 1,000 turns of 32 swg enamelled wire tapped at 250 turns, each layer being interleaved with paper. Over this a layer of paper or empire cloth is wound and then the secondary with 100 turns of 28 swg enamelled wire. The primary should then tune to 50 kc with a 500 pF capacitor, or thereabouts. The frequency is not critical so that a certain amount of divergence from these figures is permissible. The coil is mounted by cutting a piece of wood so as to be a tight push fit into the core hole; this wooden pillar is then screwed directly to the chassis. A gap of at least $\frac{1}{2}$ in. must be allowed between the winding and the chassis to avoid losses.

INPUT TRANSFORMER

This is a standard microphone transformer as used for moving coil microphones, with a ratio of 40 or 50 to 1. The design of the playback head depends to a certain extent on this ratio as the optimum performance is obtained when the combination of the head and transformer are self-resonant at 10 kc or a little over. The inductance of the head, L_h , when transferred to the secondary equals $N^2 L_h$ where N is the turns ratio of the transformer. This inductance should resonate with the sum of the transformer secondary and the first valve input capacitances. The transformer should be as small as possible and should be screened with either Mumetal or at least 1/16th in. of soft iron or mild steel. Mumetal is far preferable, but it is expensive and not easily obtained. However, if the transformer can be mounted in a short length of seamless steel pipe or conduit with the ends plugged with a thick piece of steel, the hum pick-up should not be excessive. The transformer should be mounted so it can be rotated while the amplifier is working, to find the optimum position.

CORRECTION CHOKE

This should have an inductance of about .1 H and a Q of at least 20. It should also be small to reduce hum pick-up. The winding from an old microphone or input transformer is probably the best for this and if the inductance is not high enough to

tune to 10 kc with a 3000 pF capacitor, an iron dust core or, even better, a piece of ferroxcube may be placed inside. Screening to eliminate hum may be made from heavy gauge tin plate soldered into the form of a well-fitting box, remembering that a space of at least half the diameter of the coil should be left clear all round. The coil may be mounted in the box by first putting a layer of wax in the bottom of the box, then laying the coil on top and finally filling the whole up with wax.

RECORD LEVEL METER

This is best constructed using a bridge type instrument rectifier and a 500 μ A meter. This is simply an a.c. voltmeter to read up to 250 V and if cost is of importance, a pair of terminals may be fitted so that a normal a.c. reading test meter may be connected when recording. Standard a.c. meters do not have a good frequency response so a built-in meter is preferable. It should have a suitable series resistance (200 K—500 K) of the high stability type which is adjusted so the meter just reads full scale on peak modulation. By using a high series resistance, the effect of the non-linear characteristic of the rectifier is minimised so that, in combination with the cathode follower circuit for recording, the distortion usually associated with rectifier meters is avoided.

It should be mentioned here that the capacitor shown in shunt with the input side to the rectifier serves to by-pass any bias current reaching this point, and so avoids a spurious zero reading when there is no signal.

Circuit 2.—Construction of the advanced amplifier should follow the general lines given above. However, it would be more suitable to have a separate power pack and so keep the units smaller and reduce the possibility of hum pick-up. The oscillator coil is similar to that already described apart from the secondary, while the anode coil of the Class C amplifier may be wound on a similar former with the same overall number of turns. The two secondary windings should have 100 turns each with a variety of tapings on one, to provide for variation of the bias current. The oscillator and amplifier should be separately screened and the coils placed at right angles to each other to avoid feedback.

The play—PA—record switch is a 6 pole three-way wafer switch which can be accommodated in two banks, although three wafers may simplify the wiring and reduce the possibility of introducing feedback. This also allows for including the refinement of a red light to indicate at a glance when the amplifier is set to record.

The wiring of the motor switching for forward/rewind is relatively simple and should be on the lines indicated in Fig. 44 (A). If no three-way switch is available suitable for breaking mains, the two motors may be switched separately with toggle switches. A disadvantage, however, is the possibility of switching on both motors at once. One way to avoid this is to use one two-

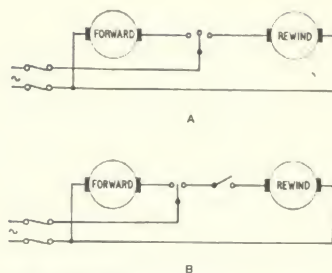


FIG. 44. MOTOR SWITCHING CIRCUITS.

way and one on/off switch as in Fig. 44 (B). Of course the braking arrangement of Fig. 24 cannot be employed if separate toggle switches are used.

4

HEAD CONSTRUCTION

THE most difficult task for the home constructor is in the manufacture of the heads. The results obtained will stand or fall by the success with which this is executed so it cannot be stressed too strongly that each stage of the work should be thought out carefully before proceeding in order that the best possible result is obtained.

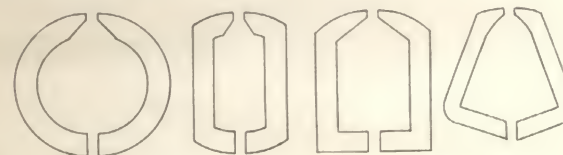


FIG. 45. TYPICAL COMMERCIAL HEAD LAMINATION SHAPES.

When a commercial head is made, laminations are stamped to a suitable shape of which samples are shown in Fig. 45 and then put through a complicated heat treatment. After this, the laminations are only machined where absolutely necessary. Mumetal and the like are very easily affected by either temperature or straining, loss of permeability being the result of failing to follow this procedure.

This process is denied to the home constructor who has to start with laminations already stamped and heat treated for a different purpose. However, it is possible *with care* to achieve results almost as good with the heads to be described.

The requirements of this head are: that it should be .1 ins. wide to afford dual track working; it should have a curved face to ensure true contact with the tape; it should be of balanced construction to reduce hum pick-up; and it should be of low impedance for ease of construction.

Fig. 46 gives a general idea of the finished head. The starting point is to find some Mumetal or Permalloy C laminations (usually painted blue). They should not be more than 1 in. along the longest edge, such as Magnetic and Electrical Alloys No. 187. The piece required is the U or E and if the laminations are .015 ins. thick, the total number required will be 28 or, allowing for spoilage, say 33—which is a stack $\frac{1}{2}$ in. thick. If the laminations are thinner, it will mean more work, but the resulting head will be more efficient. The final stack thickness is, of course, the same.

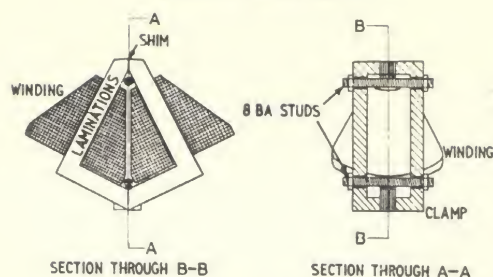


FIG. 46. CROSS SECTIONS OF A COMPLETED HEAD.

Now, having obtained the "raw material," each lamination must be cut with tin snips as shown in Fig. 47, first diagonally and then across the small corner. The latter operation should be performed accurately to avoid too much grinding later on.

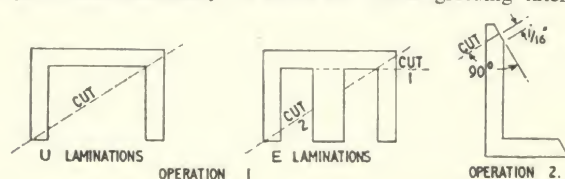


FIG. 47. METHOD OF CUTTING STANDARD "U" OR "E" LAMINATIONS TO A SUITABLE SHAPE.

When cutting the laminations, it is essential to avoid bending the part that is to be used. (Bending the part cut away does not matter.)

Next, a temporary clamp should be made to hold the laminations while the inside faces are ground. This can be made from two $\frac{1}{8}$ in. pieces of steel as shown in Fig. 48.

The holes for the locating pegs are marked so that a lamination touching the pegs will have its cut edges just level with the side of the clamp X—X. Both halves of the clamp are then drilled together with the sides X—X aligned. The pegs are driven into one half so as to protrude $\frac{3}{16}$ in. and the corresponding holes on the other half slightly enlarged to clear them. Finally put both halves of the clamp together in a vice with the side X—X just proud of the jaws and file the edges with a superfine file till the clamp is absolutely flush with the jaws of the vice. In this way, the edge is made absolutely square with the clamping surface.

Next, assemble six laminations into the clamp after painting them with a good cement (e.g., Durofix) on each side. The blue paint will probably dissolve in the cement, but this does not matter. Before finally clamping up, true the edges of the laminations as far as possible, keeping each one pressed against the pegs.

The cut edges should now be slightly proud of the clamp so

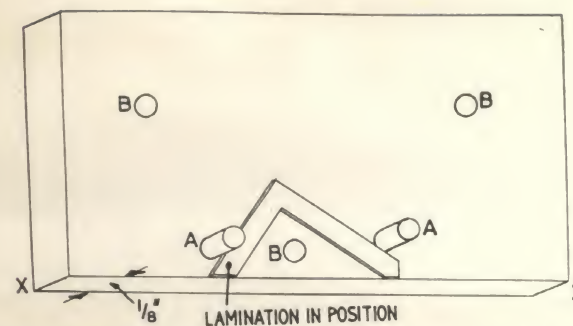


FIG. 48. TEMPORARY CLAMP FOR GRINDING LAMINATIONS. ONLY ONE HALF SHOWN. A—STEEL PEGS DRIVEN INTO ONE SIDE OF CLAMP—CLEARANCE HOLES IN THE OTHER.

that they may next be ground down to it. The clamp should be left till the cement has had time to harden. Great care should be taken to grind the laminations gently and slowly and not to grind the edge of the clamp more than is necessary for the final touches. Do not use anything other than a fine carborundum stone and do it a little at a time. Now unscrew the clamp carefully and clean it before repeating the process. Two stacks of 6 and two of 8 laminations should be made and ground in this manner.

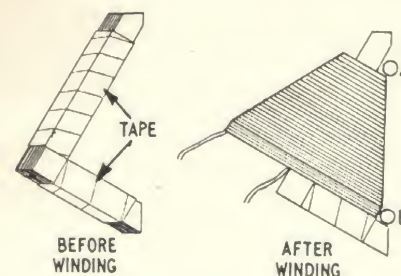


FIG. 49. SHOWING THE PROCEDURE FOR WINDING COILS ON LAMINATIONS.

The next operation is the winding of a coil on each stack of laminations. The number of turns for the record/playback stacks will vary slightly, depending on the input transformer ratio, a 40:1 transformer requiring about 70 turns per stack. For any other ratio the number of turns per stack is found from: $N = \frac{2800}{R}$ where N is the number of turns per stack and R is the transformer ratio.

Given the number of turns, the wire gauge is chosen so that the winding just about fills the available space as shown in Fig. 49, room being left for 8 BA screws at A and B. Single silk enamel wire is best as it clings together well and the turns will not slip.

If the number of turns is 70 per stack, then the gauge may be 36 swg, assuming that the laminations used are M & EA. No. 187.

The winding is roughly tapered to make the best use of the space. The winding operation is as follows:

- (1) Wind self-adhesive plastic tape round each leg of the stack as a basis for the winding. Two turns are ample.
- (2) Hold the short leg in a vice or clamp and wind the wire on by hand as carefully as possible in layers of successively fewer turns, to conform with the outline as shown.
- (3) Secure the final turn with a strip of tape, thoroughly paint the coil with coil dope and set aside to dry.

Make sure that the wire cannot chafe against bare laminations anywhere and see that the end leads are brought out at the thick end of the coil. The erase head stacks should be wound in exactly the same manner, but with 140 turns each.

When all the winding is done, the stacks may be put on one side to harden while the final clamps are made. Four of these are filed out from a thick piece of brass to the dimensions as shown in Fig. 50. The two 8 BA holes are placed so as to clear the laminations and windings as shown. If necessary, the clamp may be fabricated by soldering small blocks on to a 3/32 in. strip and merely using the file to clean up the edges and corners afterwards.

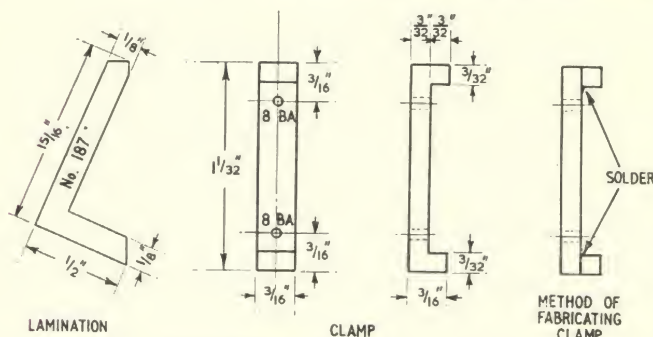


FIG. 50. CLAMP DIMENSIONS FOR NO. 187 (M. & E. A.) LAMINATIONS.

FINAL ASSEMBLY

First lay the two stacks of the record/playback head on one clamp, roughly aligning them as shown in Fig. 51, leaving a small gap between the ground faces. The other half of the clamp is put over the stacks, 8 BA screws are passed through and done up just

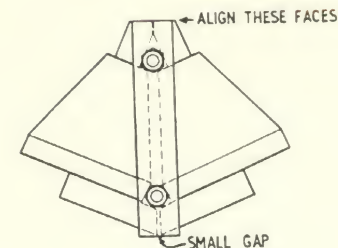


FIG. 51. ALIGNING THE LAMINATIONS PRIOR TO CLAMPING.

tight. Then, the shim material is cut to size and carefully inserted in the gaps. In the case of the record/playback head, the shims should be $\frac{1}{2}$ thou. thick. The material to be used depends upon what is available, the best being Beryllium copper hard rolled, but this is not easy to obtain. However, Mica is almost as good and can be readily obtained from old capacitors. It must be split with a razor blade until a few pieces of the required thickness are obtained. A micrometer is essential for this. It is possible to make a head with a softer material for the gap such as pure copper or even "tin foil" (aluminium), but it will not wear well, the gap tending to close up as the edges burr over, so it is not recommended.

The shim should be cut so that it will just fill the gap from side to side and be long enough to protrude inside and out. With both shims in place, slacken the 8 BA screws slightly and press the two halves of the head together, making the faces as nearly level as possible. Keeping a fair pressure on the shims in this manner, tighten the screws up fully.

The erase head is assembled with only one shim in the front gap. This is from 10 to 15 thou. and is not critical. The best material is brass foil from old mica capacitors. Being thick, the hardness is not quite so important here, but brass is still preferable to copper or aluminium. Otherwise the assembly is the same as before.

The final grinding must now be done, slowly and a little at a time, as before. The face is to be ground with a slight radius, so initially the corners must be removed and the rough outline obtained by grinding a succession of flat surfaces. Then the final grinding is done by rocking the head while it is being moved to and fro on the stone (Fig. 52). By exercising care, this will give a true cylindrical surface of constant radius.

Great care is required so that the tape will run evenly over the head and be in contact with the gap along the whole of its length. It is probable that the second attempt will be more successful than the first, so it is a good idea to make the erase head first.

If possible, the playback head should be mounted in a Mumetal box. This is expensive, however, and it may be that more every-

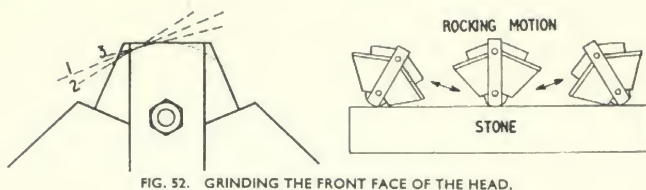


FIG. 52. GRINDING THE FRONT FACE OF THE HEAD.

day material must be used. Large section seamless electric light conduit or mild steel pipe form the basis of the screen which should have a good clearance round the head. A length about 1 in. long should be cut off and two "lids" made which will be soft soldered in position eventually (Fig. 53 (A)).

Mount the head centrally on one of the lids using the ends of the 8 BA clamping screws. Then cut a slice out of the tube so that the tape can run round the head. The geometry of this is shown in Fig 53 (B) and the complete head assembled in Fig. 54.

The head is mounted on the motor board by fixing three 6 BA screws to the second lid before it is soldered to the tube. These will allow for adjustment of the head in any direction.

Naturally, the performance of the heads should be checked

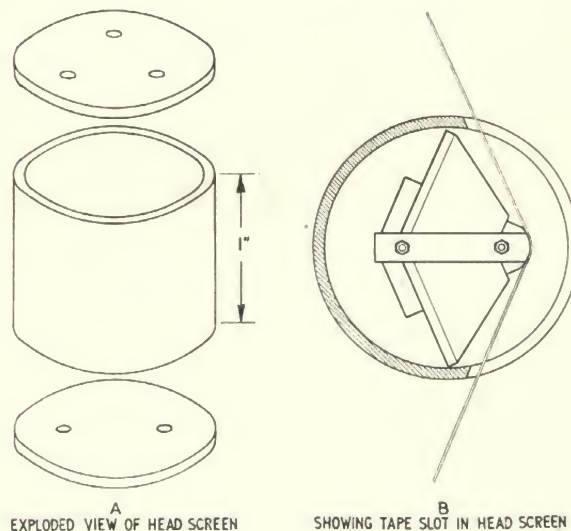


FIG. 53. CONSTRUCTION OF THE HEAD SCREEN.

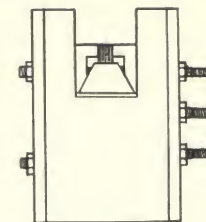


FIG. 54. COMPLETE HEAD ASSEMBLED.

before the case is soldered up. While this is being done, the case may be held together with rubber bands. When the case is soldered, use the cored solder which is specially suitable for tinning steel. If it is found necessary to open the head after it has been soldered, an old knife wedged firmly into the joint will force it open without damaging it.

OPERATION AND ADJUSTMENTS

IN addition to the equipment already described, a reel of tape will be needed. This should be of the medium coercivity type, that is, EMI H60, Scotch Boy or GEC "A". Some manufacturers regard these as high coercivity tapes and others as medium, but so long as the tape is of comparable coercivity to the above examples, no trouble will be found. Do not use any black oxide material as this will be found too difficult to erase.

MECHANICAL ADJUSTMENTS

The adjustments needed may be divided into mechanical and electrical. Taking the mechanical ones first, a piece of tape should be threaded through the recorder and the guides adjusted so that the tape runs parallel to the motor board and at the right height for the reels. When this has been effected so the tape runs smoothly and the take-up spool has sufficient drive to keep the tape just tight, the heads must be adjusted so the gaps are exactly in the centre of the contact area (Fig. 55). Then the height of the heads are adjusted so the gaps operate on only one half of the tape and the wider erase gap fully covers the record gap. The heads must also be aligned so that the gaps are at right angles to the line of the tape. This is not critical and there is no need for more than visual accuracy.

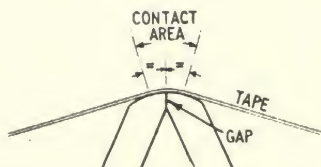


FIG. 55. SHOWING THE GAP CORRECTLY LOCATED IN THE CENTRE OF THE TAPE CONTACT AREA.

ELECTRICAL ADJUSTMENT

Now if all appears to be well, try recording some music on the tape. The result may be distorted, indicating wrong bias level which should be carefully adjusted in the following manner.

Make a series of recordings of music at a low level and vary the bias a known amount each time. Then, on playback, the setting which gives the best results for lack of distortion and sensitivity is the correct one. If the bias is too low, there will be severe distortion especially on quiet passages; if it is too high, the sensitivity is low and high frequencies will be lost. To set the bias, a low reading a.c. milliammeter is needed, remembering that the reading will be inaccurate and may only be used for comparison purposes. The bias level will only be correct for one kind of tape

and if more than one is to be used, a separate check must be made for each.

Next, re-record with no signal over one of the tracks previously made, to ensure that the erase head is functioning properly. If not, first ensure that the tape is in good contact with the head at the gap. If this is all right, then there is insufficient current through the head and the oscillator must be investigated to obtain more output or better coupling. This operation should be carried out in conjunction with the bias level setting as there is usually interaction between the two circuits.

The next operation is to adjust the correction circuits to give a flat overall response. A beat frequency oscillator and valve voltmeter are needed to do this correctly, but a good substitute is a constant frequency record providing tones from 50 c/s to 10 kc. A multi-range a.c. meter may be calibrated from this, using the amplifier with the correction circuits disconnected. If using a beat frequency oscillator, record in steps of an octave from 50 c/s to 10 kc with a distinctive break in the signal at one or two key frequencies to serve as a check. Then play back and note the output level reading at each frequency. The correction circuits may then be adjusted and the process repeated until the frequency response is reasonably level.

A steady note should be recorded for several minutes and played back to discover any wow or flutter arising from faults in the drive mechanism. The frequency of the wow should give a clear indication as to what rotating part is giving trouble. The most probable source is eccentricity of the capstan or pinch wheel. If the wow is irregular, the take-up drive should be suspect.

Finally, the record level meter is adjusted by increasing the recording level till distortion occurs. The series resistance can then be selected to give full-scale deflection on peaks at this level. Then, if the level is not allowed to pass beyond the half scale mark, the recording should be free from distortion.

As the meter movement is more or less sluggish, a steady note will give a higher reading than a short note of the same peak intensity, therefore care must be taken as to the type of music being recorded, a piano requiring a lower reading than, say, an organ, to avoid overloading.

For really high-class work, a peak reading meter, with a long time-constant, may be used, but this requires an extra stage to act as a buffer, and diode rectification, so is considered to be outside the scope of the present book.

WIRE RECORDER

THE difference in recording technique when wire is used depends mostly upon what type of instrument is required. If the highest possible quality is the aim, then the recorder should be basically the same as the tape recorder. If simplicity, economy and size are the main factors, then quite a different technique may be used. We will deal with the former instrument first.

The layout is basically the same as for the tape recorder, the wire being pulled from a spool and round the heads by a capstan and pinch wheel. The take-up is on another spool driven by a slipping belt. The guides are not needed as a slot in the head is sufficient to guide the wire. The biggest difference is that a mechanism for layer winding the wire is needed for both take-up and rewind. A general plan of the machine is given in Fig. 56.

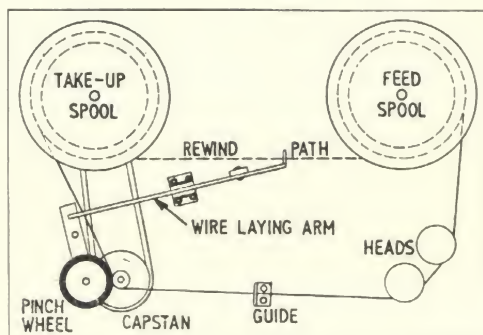


FIG. 56. PLAN OF HIGH QUALITY WIRE RECORDER.

MOTOR, CAPSTAN AND PINCH WHEEL

As the wire speed should be 2 ft. per sec., the capstan diameter for 78 r.p.m. comes out at 6 ins. This is rather large, but by no means impractical. It should be rubber tyred to obtain maximum grip, the pinch wheel being plain and of about 2 ins. diameter. The width of both wheels should be not less than $\frac{1}{4}$ in. and to retain the wire in the centre of the tyre, a guide just before the capstan is needed. The slot in the heads may do duty for this, but it means that the heads and motor must be rather close and hum

pick-up will most likely be excessive, prohibiting this layout. Preferably the guide should be a strip of brass with a narrow slot cut in it, as in Fig. 57. It should be adjusted so that the wire does not bear against the guide at all when everything is truly aligned.

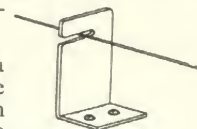


FIG. 57. WIRE GUIDE.

If a 1,400 r.p.m. drive is used, *i.e.*, a simple four pole induction motor, then the capstan must be $\cdot 35$ ins. in diameter, which is a very reasonable size and may be a steel bush fitting tightly on to the motor spindle. The pinch wheel should now be exactly the same as for the tape recorder. The guide mentioned above is needed here as well. The layout and dimensions of the two possible drive mechanisms are shown in Fig. 58. The latter is preferable as it takes up less space and is simpler to construct, and is the one shown on the general layout.

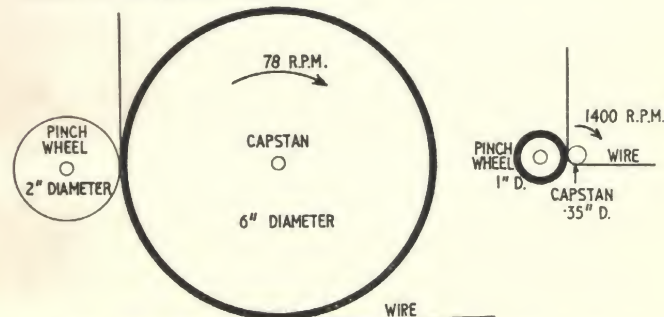


FIG. 58. PINCH WHEEL AND CAPSTAN LAYOUT FOR 78 AND 1400 r.p.m. DRIVES.

TAKE-UP SPINDLE AND PULLEY

The standard wire spool is made to fit over a boss $1\frac{5}{8}$ ins. in diameter and $\frac{5}{8}$ in. high. This then replaces the spigot used for the tape spool. A wood boss pressed over the spindle is perfectly satisfactory. A sheet metal disc 2 ins. in diameter must be screwed to the under-side of the boss to locate the spool accurately when it is pushed on. The bearing as before is obtained by using an old tuning condenser, although there is no need to use other than the standard $\frac{1}{4}$ in. spindle. The driving pulley is fitted on to the shaft below the boss and may be used as an endways location for it (Fig. 59). The size of the pulley should be such that, with an empty spool, the wire is kept tight. This is of greater importance than with tape, as, if the wire gets into a muddle owing to slack winding, it is a question of either hours of disentangling or it must be discarded.

The brake, which is very important with wire, is similar to that used on the tape model. The operation of the brake is shown

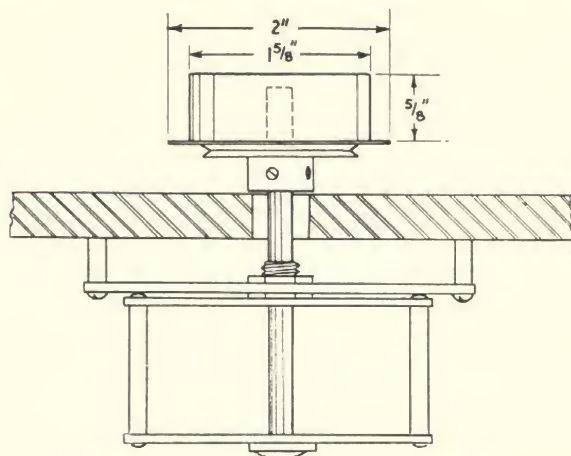


FIG. 59. TAKE-UP SPINDLE AND PULLEY FOR WIRE RECORDER.

in Fig. 60. It is essential that the motor switch should operate the brake directly, or even slightly before, the instant the forward or rewind motor is switched off.

FEED SPINDLE

A separate motor is required for rewinding, as a fast rewind is essential with wire, so that a similar wood boss to the above is pressed straight on to the motor spindle. A more positive drive may be needed here as greater power has to be transmitted. A standard Meccano cog wheel or a similar wheel is firmly fixed to the spindle and the boss is then fixed to this with two small screws.

Owing to the high speed of forward drive, a positive brake is needed on the feed spool. This is identical in design to the one on the take-up spool and is also operated by the brake switch.

To ensure that the brakes come on in the right manner, the levers should be arranged so that when stopping from rewind the take-up spool brake comes on first and when stopping from forward drive the feed spool brake comes on first. A suggested method of doing this is shown in Fig. 60.

WIRE LAYING

There are two basic methods of providing a constant speed to and fro motion. One uses two oppositely rotating threads with half nuts "flip-flopped" from one to the other when the required travel is reached. This is the normal system used on coil winding machines. The other, and simpler, method is to use a specially shaped cam in the form of a heart and driven at a steady speed. Fig. 61 shows both methods.

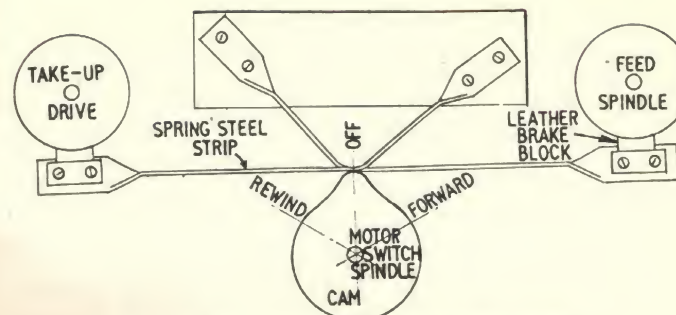


FIG. 60. METHOD OF OPERATING BRAKES FOR WIRE RECORDER.

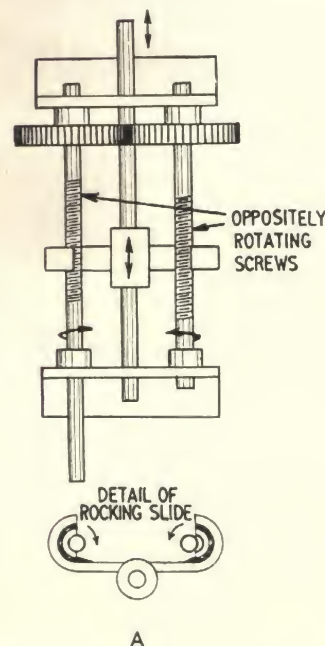


FIG. 61. TWO METHODS OF PROVIDING TO AND FRO MOTION FOR OPERATING THE WIRE LAYING ARM.

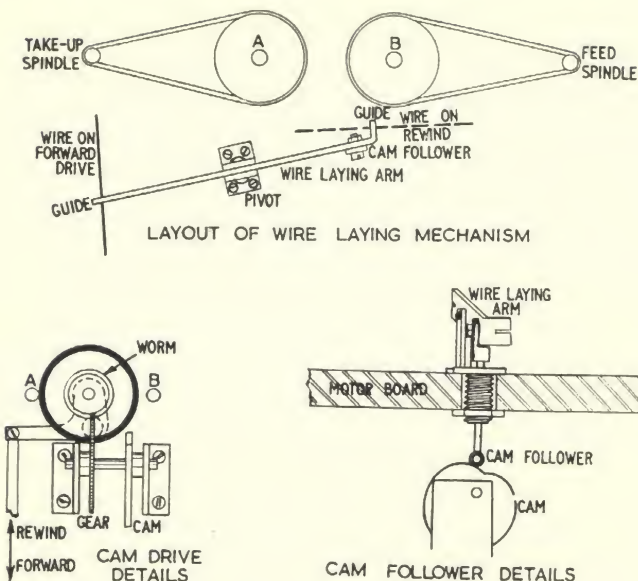


FIG. 62. ARRANGEMENT OF WIRE LAYING MECHANISM FOR HIGH QUALITY TYPE WIRE RECORDER.

The latter method is the easier to construct as, apart from the cam itself, only standard gears, etc., are needed. The layout as applied to the wire recorder is shown in Fig. 62. The cam is driven *via* a belt, then worm wheel drive from the take-up or feed spindle, depending on the direction of drive, and a cam follower transmits the motion to a rocking arm, which carries a guide at each end. The wire is put into the slot in front of whichever spool is winding up. The speed of the cam is arranged so that it rotates completely once for every 200 turns of the spool. This gives a winding pitch of 5 thou. per turn.

The drive is first *via* rubber belts running directly on the spool spindles to two $\frac{1}{2}$ in. diameter pulleys. The spindles on which these run should be about $\frac{1}{8}$ in. diameter and alternatively drive a rubber disc by friction. The latter runs on a spindle mounted on a pivoted arm, which is moved by the motor switch from forward to rewind. Rigidly coupled to the disc is a worm wheel on the same spindle which engages with a gear on a small cross shaft. The latter shaft carries the cam itself. If the rubber-rimmed wheel is 1 in. in diameter, the required ratio will be obtained with a gear of 25 teeth. No special accuracy is required in the bearings except those on the

cross shaft, which should have the minimum of side play. The layout is suggested in the diagram, although individual variations may be adopted so long as the main essentials are retained. It is advisable to spring-load the rocking guide arm so that the cam follower presses firmly on the cam.

Every item used in the layer winding mechanism can be obtained or easily made from Mecanno, except for the cam itself. This must be carefully and accurately made or the winding will be uneven, so a more detailed description of its construction follows.

MAKING THE CAM

The requirement for the heart-shaped cam is that, for a constant speed of rotation, a cam follower should move at constant speed in one direction and then abruptly change direction and move at the same speed in the opposite direction. A spiral fulfils the first part of the requirement so that the shape of the curve is a spiral. After 180°, the spiral is reversed so as to be a mirror image of the first half (Fig. 63). As the special equipment needed to cut a spiral is not likely to be available, the cam must be carefully marked out and then filed to shape.

The total throw needed at the guide is $\frac{1}{2}$ in., but the cam does not necessarily have to have a throw of this amount, as the guide is operated *via* a lever. However, any inaccuracy in the shape of the cam will be magnified in the ratio of the lever. This means that the throw of the cam should be as large as is practicable. If the minimum radius of the cam is taken as $\frac{1}{4}$ in., then for a full throw of $\frac{1}{2}$ in. the maximum radius must be $\frac{3}{4}$ in., giving $1\frac{1}{2}$ ins. diameter. This is quite practical so long as the brackets are arranged to give sufficient space for the cam. If size is of consideration, a $\frac{1}{4}$ in. throw reduces the diameter needed to 1 in. and is about the smallest practical cam that can be made in this manner.

Once the rough dimensions are chosen, the blank can be cut. The blank may either be a 16 swg steel disc brazed to a brass boss or, if a lathe is available, it can be cut from the solid so that the boss forms an integral part of it. The boss must be drilled and tapped twice at right angles for its eventual fixing to its shaft (Fig. 64).



FIG. 63. THE DERIVATION OF CAM SHAPE.

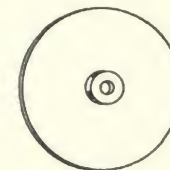


FIG. 64. BLANK FROM WHICH CAM IS MADE.

To mark out the cam, a very simple jig is needed (Fig 65).

Two straight edges are clamped so they are parallel and about $1\frac{1}{2}$ ins. apart. The blank is fixed to a shaft and collars are placed

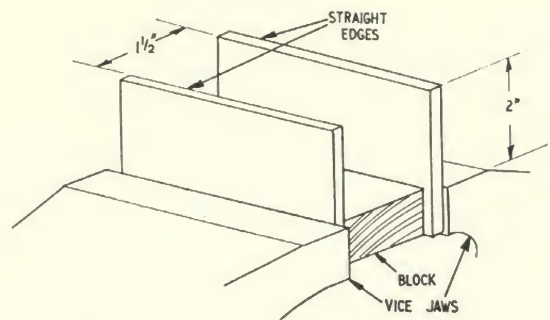


FIG. 65. SET-UP FOR MARKING OUT THE BLANK.

on each side of it. These collars are made a good fit on the shaft with an outside diameter D , such that : $\frac{\pi D}{2} = T$ or $D = \frac{2T}{\pi}$ where T is the required throw of the Cam.

Thus for a $\frac{1}{2}$ in. throw $D = \frac{1}{\pi}$ or .318 in.

Now a scribe is clamped to one of the straight edges and adjusted so that when the blank is rolled along on the collars it will mark the face of the cam. It is important that the point of the scribe is on a level with the axis of the shaft. The cam is marked as shown in Fig. 66 and, with the scribe set at point A, the cam is carefully rolled away from it.

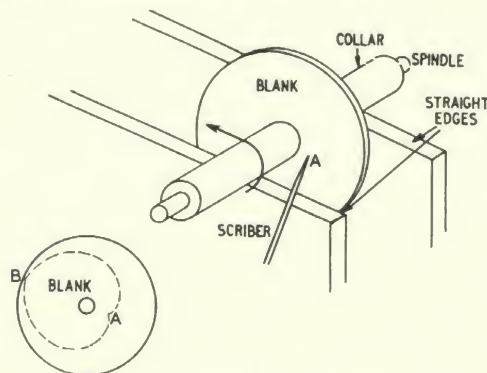


FIG. 66. MARKING OUT THE BLANK.

If no slip has occurred, the scribe should pass through point B. Then the cam is made to roll towards the scribe, starting from point B, and the other half is marked out. Possibly one or two shots will be needed to get this just right so that it is as well to chalk the cam and only allow the scribe to touch it lightly, then, if a mistake is made, it can be rubbed out. The operation of rolling the cam in this manner that neither side slips needs a little practice and can be facilitated by sticking rubber strips to the two straight edges.

Once the cam has been marked, it should be cut and filed as near as can be done to the line. Then by repeating the marking operation, the shape can be checked and improved until a satisfactory cam is produced. The surface should be as smooth as possible so that the cam follower does not move jerkily. When the recorder is first used the winding should be carefully watched to see if the cam is cut accurately and, if not, any errors should be corrected by careful filing.

HEAD CONSTRUCTION

The construction of the head is the same as for the tape head, except that it need only be two or three laminations thick. The neatest way of making the slot is to construct the head with two 15 thou. laminations each side and a 5 thou. one in the centre cut away at the face, as in Fig. 67. If no 5 thou. laminations are avail-

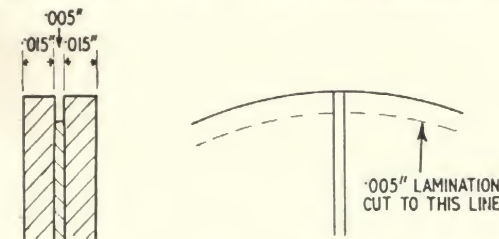


FIG. 67. WIRE HEAD USING CUT DOWN .005" LAMINATIONS TO PROVIDE A SLOT.

able, then two 15 thou. laminations are filed very carefully at the face so as to make a slot when put together (Fig. 68).

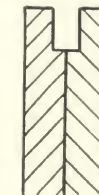


FIG. 68. WIRE HEAD USING TWO FILED DOWN .015" LAMINATIONS.

To retain the same order of inductance as for the tape heads, about 50 per cent. more turns will be needed.

The shim for the play/record head need not be less than 1 thou. as the speed is higher and the gap is no longer a serious limiting factor to the high frequency response. The slots in the shims are made with a razor blade after the heads are assembled. It is important that the slot is quite smooth for the wire to run through without friction.

AMPLIFIER

The amplifier for the wire recorder is identical with that used for tape. The coercivity of wire is about the same as that of high coercivity tape, but the thickness is some 6-8 times that of the tape coating. This means that, using a speed of 2 ft. per sec., which is only just over three times the speed of tape, the highest frequency that can be recorded is lower than that for tape. This will affect the correction circuits slightly, but not more than can be taken care of by normal adjustments.

THE SIMPLER TYPE OF WIRE RECORDER

This does not use the principle of constant wire speed, but of constant take-up spool speed. If a large take-up spool is used, the increase in diameter when full, and therefore the wire speed, will not vary by more than 10 per cent. Provided the same piece of wire always goes through the head at the same speed, no great trouble is experienced. It is, however, of greater importance to ensure even winding to avoid wow. It is this difficulty of avoiding wow that limits the performance of this particular type of machine.

DRIVE MOTOR AND SPOOL

A complete gramophone motor and turntable of the rim drive type is used to drive the spool. At 78 r.p.m. the spool diameter must be 5.9 ins. It is screwed to the turntable and very great care must be taken to get it absolutely concentric with the spindle. The spool itself must be constructed. The simplest way is to use 20 swg brass or aluminium sheet and form it round a wooden mandrel 5.8 ins. in diameter. Heavier gauge discs form the sides of the spool. The constructional details are shown in Fig. 69. A hard wood block is turned to a diameter of 5.8 ins. While it is still held in the lathe chuck, a $9/32$ in. hole is carefully drilled in it. The wood is then cut so as to be exactly $\frac{1}{2}$ in. thick with the sides quite parallel. The 20 swg sheet is cut to a strip $\frac{1}{4}$ in. wide and wrapped round the wooden mandrel, the edges carefully butted and screwed in place with countersunk wood screws. Two 18 swg discs are cut $6\frac{3}{4}$ ins. in diameter with a central $9/32$ in. hole and screwed together, making sure that there is no gap between the flanges and the centre. A small hole is drilled in one flange at the bottom to

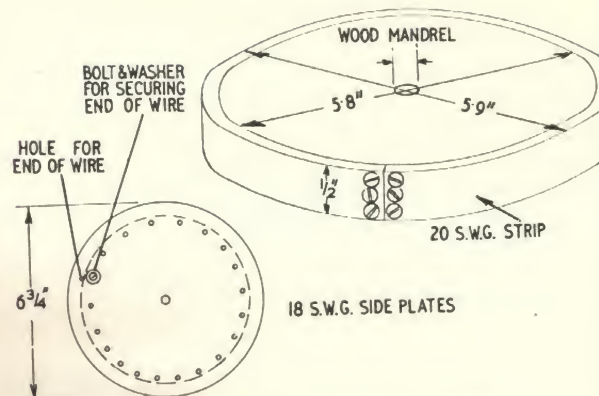


FIG. 69. CONSTRUCTIONAL DETAILS FOR WIRE SPOOL.

pass the wire through and a screw and washer in the centre boss for anchoring the end of the wire.

The whole spool should be placed on the turntable and spun to see if there is any eccentricity. The centre hole can be carefully enlarged to take up any error if necessary. When all is aligned, three screws fixed up through holes in the turntable into the boss will hold the spool in place; alternatively, the spindle may be drilled and tapped to take a screw with a wing nut soldered to its head. The latter method does not allow any special adjustment of the spool and the centre hole must be right first time.

The layer winding mechanism is similar to the one already described. It is somewhat simplified by only being driven by the take-up spool. This means that on rewind the wire is not correctly layered, but this is sacrificed for simplicity and is permissible for this type of machine. The other difference is that the cam follower is connected to the head assembly which moves on two $\frac{1}{4}$ in. pillars sliding in bushes. Thus the heads act as the only guide for the wire and operate on both forward and reverse winding. The layout suggested for this is shown in Fig. 70.

Attention should be paid to the construction of the contact point on the cam follower: this should not be too large, otherwise the correct travel will not be obtained; if too small it will wear badly; about $1/16$ in. is ideal. Also there must be clearance so the follower can reach right to the bottom of the travel allowed by the heart shape, otherwise some of the travel will be lost.

The drive to the cam is via a rubber band directly round the turntable spindle which drives a pulley $1\frac{1}{8}$ ins. in diameter. This pulley is on a vertical shaft held by a bracket shown in Fig. 71. At the lower end of this shaft is a worm wheel driving a 25 tooth wheel

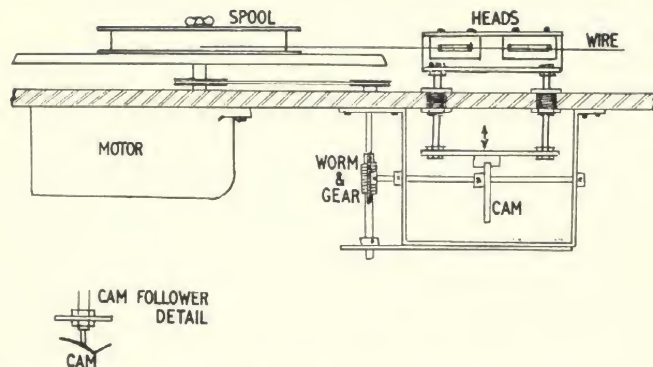


FIG. 70. ARRANGEMENT OF WIRE LAYING MECHANISM FOR SEMI-CONSTANT SPEED WIRE RECORDER.

on a horizontal shaft. On this shaft is the cam which must have a $\frac{1}{2}$ in. throw if the heads are to ride directly on it. If a rocking arm is used, the throw of the cam may be made to suit the particular layout.

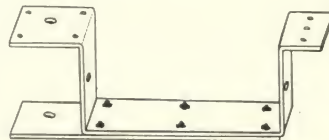


FIG. 71. CONSTRUCTION OF BRACKET TO CARRY MECHANISM OF FIG. 70.

In order to free the turntable on rewind, the idler between the motor and turntable may have to be held off, depending on the type of motor used. Usually, the spring holding it on is so light that this is not required, but if it is, a wire link between the motor switch and the idler can be contrived so the idler only operates on forward drive.

The brake operates on the rim of the turntable and the pad is a V-shaped piece of leather as shown in Fig. 72. Otherwise, the



FIG. 72. BRAKE BLOCK FOR SIMPLE WIRE RECORDER.

operation is the same as for the other wire recorder.

The rewind spool is mounted exactly as in the previous model except that any drive to the layer winding gear is omitted.

It is quite possible to mount this type of recorder on a gramophone motor board so that by removing the take-up spool the gramophone can still be used. This makes a very useful unit

which is fairly compact and has great advantages for those with a library of disc records.

ADJUSTING AND OPERATING OF WIRE RECORDER

No alignment of the heads is needed with wire other than to make sure that it runs straight and freely through the slot.

The layering mechanism needs a certain amount of careful adjustment to ensure that the spools are wound evenly, and tightly, and do not fill one side more than the other.

The hold-back friction pads must be checked to ensure that sufficient tension is obtained to wind the wire tightly and the brakes must be set so the braking action is firm but not fierce when the motors are switched off.

Instructions given for amplifier adjustments for tape hold good for the wire recorder.

The operation of a wire recorder calls for a certain amount of care, as a bad tangle will probably occur if the wire gets loose. With no automatic stop mechanism, the motors must be stopped before the wire has run out in either the forward or reverse direction. As the wire is difficult to see, it is essential to check that the wire is correctly threaded and tight before switching on either motor.

If wire has to be joined, it can be tied in a reef knot and the loose ends snapped off. But if this is likely to be done, it is necessary to have the guides at least 10 thou. wide or the knot will jam. A break in wire very often means a tangle as well, so the odd tangled end is usually thrown away unless the break is in the middle of a spool. The most important thing is not to break the wire. When a new wire recorder is being tried out, it is very wise to wind a few yards of wire on to a spare spool and use this for testing.

THIS chapter is included for those who have made a recorder and who wish to obtain the best possible results from it; it is concerned more with acoustic than with electrical problems.

MICROPHONES AND THEIR USE

The most popular types of microphones are the moving coil and diaphragm crystal types, the former feeding, *via* its matching transformer, into an impedance of about 100 K and the latter of about 5 megohms. Both types are pressure microphones, *i.e.*, they operate in accordance with the pressure of the air upon them and their diaphragms do not move appreciably. As they are of a size comparable to the wavelengths in air of the higher frequencies, these frequencies are received best from positions in front of the diaphragm. In other words, they are slightly directional at the higher frequencies. If all-round coverage is required, then the microphone can be pointed vertically upwards, but this causes a slight general high-note loss. Both types give about the same output and there is relatively little to choose between them.

The ribbon or velocity microphone is often regarded as the best for high quality and it does have a good frequency characteristic. On the other hand, it is directional in a figure of eight pattern (Fig. 73). The directional properties may be an advantage or a disadvantage, depending on the particular use to which it is put, as is mentioned later. This microphone is the only one whose response is proportional to the instantaneous particle velocity of the air, instead of to the instantaneous pressure variations. This gives it its directional properties (as sound coming from the side

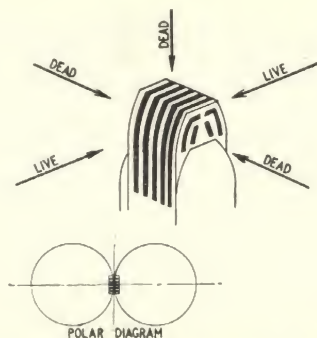


FIG. 73. SHOWING DIRECTIONAL SENSITIVITY AND POLAR DIAGRAM OF VELOCITY (RIBBON) TYPE MICROPHONE.

causes no movement of air between the pole pieces and so gives zero output to the amplifier) and also makes it unsuited for close speaking (except crooning). The output of the ribbon microphone is in general lower than that of the two previous types, although some modern ones have almost as much.

The higher quality type of crystal microphone where the sound waves act directly on the crystal, typified by the sound cell type, comes in the same class as the ribbon for cost, quality and sensitivity. Otherwise it has similar properties to the diaphragm type. It also has one other distinction, that it is basically omni-directional, the operating surface being so small that directional discrimination of the higher frequencies is almost totally lacking. This property is particularly useful for occasions where the voices of a group of people must be picked up equally or where the people move about, as when recording stage productions.

Condenser microphones are extremely good, but require a built-in pre-amplifier and are generally very delicate. Carbon microphones are of little use here, but for the opposite reason; the quality is generally poor, they need d.c. energising and are liable to hiss. Otherwise they are robust and simple.

Whatever type of microphone is used and however expensive it is, it cannot give good results in unsuitable conditions. When professional recordings are made, they are done in very carefully designed studios, sound proof and with acoustically treated walls. It is not surprising then, that a microphone placed in front of a band in a village hall or old army hut gives results reminiscent of an old horn gramophone. The fault lies not with the microphone or recording gear, but with the acoustics of the "studio." Very often the village hall is the only place available for making the recording or, more often, the recording engineer has no choice in the matter. When this is so, it becomes a question of what can be done to improve the acoustics of an unsuitable room. There is only space for a few very practical hints in this book, but if they are followed, considerable improvements can be made.

The usual trouble is that there are too many echoes, the room is too "live" and its reverberations are frequency selective. The solution to both troubles is to hang absorbent material round the room. The problem is to absorb sound in this way, of the right frequency and in the right places. Carpets, curtains, draperies, etc., absorb high frequencies, but they pass low frequencies, which will then be reflected from any hard surface behind. A thin, hard surface, such as cardboard, over a thick absorbent material will reflect the high frequencies and pass the low frequencies which are then absorbed in the material behind. These general principles give the basis for choosing the right kind of absorbent required.

The positions for absorbents must be tried out in practice as a rule, but a very rough guide can be given for a few cases. A long narrow room should have some absorbent down the sides and on the floor or ceiling, if possible half way down. An audience is a good absorber of all frequencies, this fact is liable to be forgotten

when trying out in an empty room. In such a case, an audience is a great advantage in spite of the unwanted noises introduced in the way of coughs, etc. A dance hall often proves better when the floor is occupied, as the reflected sound from the hard wood floor is absorbed. If the room is small and square with bare walls, the absorbent should be in the middle of one or two walls and on the floor, in the form of a carpet. Also, introduction of a screen or a piece of furniture somewhere to break up the side-to-side echoes will produce a great improvement.

If the room itself cannot be treated, as so frequently happens, some improvement can be achieved by shielding the microphone from sound coming from unwanted directions. Overcoats hung round the back of the microphone make a good emergency absorbent screen. If a speaker is sitting or standing in front of a desk so that it is between him and the microphone, it should be damped to prevent its particular resonance from affecting the sound. This may be done by placing thick felt on it, or, even better, by using felt with some soft paper on top of it, as this will assist the high frequencies and improve the clarity.

Often a good spot for the microphone may be found by the old method of clapping and listening to the echoes in various places until a spot is found with the least objectionable echo.

If the microphone is of the directional type, try turning it round to cut out unwanted echoes. These often come at right angles to the wanted sound, so this is one place where the velocity microphone is invaluable. It may also be placed between two wanted sounds, as when two people are talking, so that they will both be reproduced equally.

For small orchestras a pressure type microphone is often best, equally spaced from the instruments, but pointing towards the weakest instruments, e.g., violins. The foregoing remarks apply where recording is required independently of other sound requirements in the hall. If it is possible to co-operate with PA engineers, however, better results can be obtained. An outlet is obtained from the PA system, to save using a separate microphone. In these circumstances very good results can be achieved by using ribbon microphones with the orchestra, in conjunction with careful arrangement of the orchestra (the conductor must, of course, be consulted about this). Strong instruments that might otherwise "drown out" the weaker ones can be placed reasonably near the microphone, but on or near its "dead" axis.

If the use of the microphone is to be limited to home use, there is less echo trouble, but the frequency selectivity of small rooms may be a problem, especially if playback is to be in the same room, as whatever effect there is is doubled. Usually the effect is an accentuation of the fairly low frequencies and some increased high note reflection is needed. Sheets of cardboard or wallpaper covering the drawn curtains, carpet and chairs give the desired effect in most cases.

If a microphone is to be used out of doors where extraneous noises are a nuisance, a well-padded box can be a very valuable piece of equipment. It should be as large as possible, e.g., an old tea chest, and the padding should half fill the box. The microphone should then be placed just inside the box and pointing outwards. Parabolic reflectors for focusing the sound from one direction only are rather beyond the scope of most people and are very tricky things to make and use, so they are not recommended unless considerable experience has been had in this field.

It is always invaluable to use a pair of monitor earphones so that the quality can be checked before any recording has taken place. They are also useful to monitor the recording and to assist in handling the volume control if the sound intensity varies. In the latter connection, it is worth while noting that "live" music has many unexpected high intensity sounds, which may overload the equipment. These peaks have already been taken care of in radio programmes, or professionally-made records, and so a higher relative level may be set without danger of overloading.

When recording from the radio, the best connection to make to the set is across the speech coil of the loudspeaker as it is readily accessible and is not likely to carry d.c. voltages.

Do not try to record *via* the loudspeaker with a microphone, as unnecessary distortion may be introduced and the acoustics of speaker, microphone and room all "colour" the sound and make the result sound unnatural.

It is often necessary to mark a particular section of a recording. This can easily be done, when using tape, by sticking a small piece of coloured plastic tape to the back of the recording tape. The edges will show through quite well when wound on to the spool. This method is not suitable for use with wire recorders and careful timing is the only solution.

The care of a valued recording is always important and apart from making sure that it is not erased, the following points may be useful.

Tape should not be allowed to become too hot or too damp and it should always be left wound up absolutely evenly, otherwise the exposed pieces of tape will tend to crinkle. A field sufficiently strong to demagnetize the tape is unlikely to be encountered normally, but this point should be remembered if there are strong a.c. fields about. Wire is less liable to be damaged by atmospheric conditions than tape, but care must be taken that it cannot unwind and tangle.

Finally, if the reader has never before heard his own voice recorded, do not be surprised or blame the recorder if he cannot recognise himself. Nobody ever does recognise his own voice at first, as it is ordinarily heard *via* bone conduction and the nasal passages, which makes it sound entirely different from the normal sound heard by others. Thus for speech quality tests it is always necessary to have someone else to do the speaking, or the judging

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